A Model for Estimating Water Demand Functions for Agriculture in Bahrain

By

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Outline

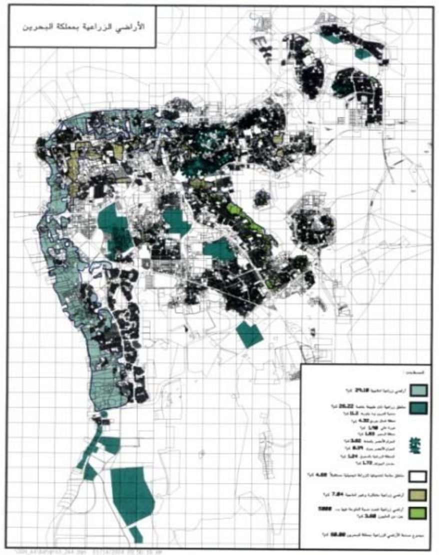
1. The Objectives.
2. Basic Agricultural Data and Facts.
3. Agricultural Water Use and Trends.
4. Data and Methods.
5. Statistical Results.
6. Model Estimation.
7. Conclusions and Policy Implications.

Objectives

- to determine and analyse factors that influence water use in agriculture; and
- to develop water demand functions for agriculture

Basic Agricultural Data and Facts

- Agriculture in Bahrain has a limited potential
- Confined to a narrow relatively fertile strip along the northern and western coasts (the so-called the green belt)
- Suffers from serious challenges and constraints:
  - unfavorable climatic conditions,
  - limited natural resources,
  - poor cultivation and farming practices,
  - small farm holdings,
  - land tenure system problems,
  - soil salinization and drainage problems,
  - poor quality of irrigation water and low irrigation efficiency - 65% (2001)
  - lack of financial incentives; and
  - absence of proper agricultural planning



Agriculture … Past and Present

The above photo is after Zubari, W. K., 2009.

Key agro-economic indicators:

- In 2012, contribution of agriculture (including fishing) to the GDP (current prices) was 0.32%
- Agriculture employment - only 5,524 louberers (2003), a 1.54% of the total workforce - 35.8% decline from that reported in 1991
- Per capita share of cultivated land - 0.0027 (2012)

3. Agricultural Water Use and Trends

- Main sources: groundwater, treated sewage effluent (TSE) re-use, and blended water from piped supply.
- Other minor sources.
- Metering and water charges.
- Water use for agriculture and cultivated area both show declining trends.

Agricultural water use by the main sources of supply, together with the trends in irrigated land and irrigation water requirements 2000 - 2012

Year	Water use by source (Mm^3)			Total water use (Mm^3)	Cultivated area (ha)	Irrigation requirements (m^3/ha/year)
	Groundwater	TSE	Piped water			
2000	159.5	14.6	3.0	177.1	4199	42177
2001	137.4	15.4	3.3	156.1	3916	39862
2002	141.9	14.1	3.3	159.3	3681	43276
2003	135.9	18.8	3.6	158.3	3571	44329
2004	123.2	22.6	3.6	149.4	3924	38073
2005	110.8	24.0	3.3	138.1	4644	29737
2006	104.4	29.5	3.1	137.0	4454	30759
2007	98.8	32.2	3.4	134.4	4344	30939
2008	97.6	39.1	3.7	140.4	4219	33278
2009	95.0	36.9	3.2	135.1	4104	32919
2010	92.8	36.1	3.9	132.8	3980	33367
2011	89.9	36.5	4.1	130.5	3875	33677
2012	84.4	40.2	4.3	128.9	3538	36433

Source: Compiled and adapted from different sources: Al-Noaimi (2004); Al-Noaimi (2005); Al-Noaimi (2009); AASB (2009); the Water Authorities Abstraction Records; and author estimates.

4. Data and Methods

- Data set were derived from a country-wide cross-sectional survey of 111 farm plots (Random sample - 10.2% of the total population)
- Metered consumption data of 143 farms were thoroughly analyzed - Matching well number with plot number
- Population Parameters: Mean of average monthly consumption 89.9 m^3/ha/day - Standard deviation 54.5 m^3/ha/day - Population size *N* = total number of productive farms = 1,093 farm units). Sample size:

$$E = Z_{\alpha}/_2 \frac{\sigma}{\sqrt{n}} \sqrt{\frac{N-n}{N-1}}$$

where *E* is the maximum tolerable error (taken for this research at 10 deviation units), $Z_{\alpha/2}$ is the standardised *t*-statistics at the desired confidence level, σ is the standard deviation estimate, *n* is the sample size, and *N* is the population size [Johnson, 1996; Cochran, 1977].

- A survey questionnaire was designed
- Attempts to obtain additional data from FAO Team survey failed - Matching problems
- Average water consumptions (m^3/month) for each farm were calculated using the same matching procedure
- Average monthly water consumption (m^3/month) for farms supplied by TSE were calculated from consumption figures and matching plot number with the farm connection code
- Average summer (March - August) consumption, and average winter (September - February) consumption were computed
- A number of new variables were created
- A set of dummy variables were also created

5. Statistical Results

Summary descriptive statistics on the main farm and irrigation variables

Variable	Mean	Minimum	Maximum	Std. deviation
Average consumption	5461.8	286.2	23869.0	4180.6
Average summer consumption	5846.0	307.6	26471.2	4745.4
Average winter consumption	5050.8	295.5	23914.6	4485.6
Plot area	3.1	0.20	18.1	3.2
Gross cultivated area	2.6	0.16	18.0	2.9
Gross irrigated area	2.2	0.05	14.5	2.6
Area under protected agriculture	0.3	0.00	2.9	0.5
Irrigation water requirement	3264.0	109.3	14017.2	2805.4
Average irrigation frequency	1.3	0.50	6.0	0.61
Average irrigation freq. summer	1.5	0.30	5.0	0.69
Average irrigation freq. winter	1.2	0.50	7.0	0.68

Notes: Average consumption and summer and winter average consumptions are in m^3/month. Plot area, gross cultivated area, gross area under irrigation, and area under protected agriculture are in ha. Irrigation water requirement is in m^3/ha/month. Average irrigation frequencies are in time/day.

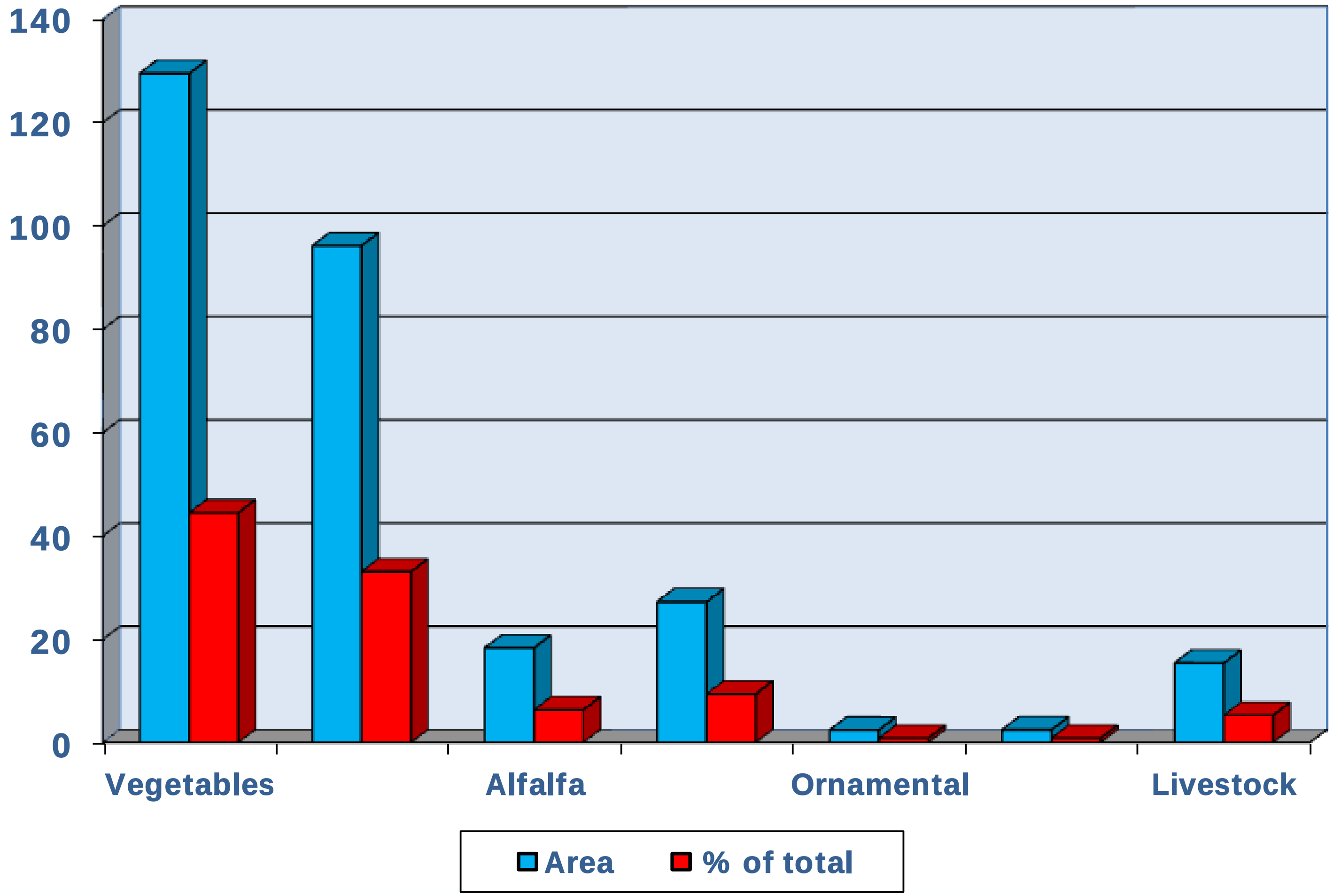
Summary of main statistical findings

- Seasonal variability is about 16%
- Average irrigation frequencies in summer exceed those in winter by slightly more than 28%
- Average application rate is 109 m^3/ha/day - consistent with that reported for the base year
- The median value of average irrigation water requirements was 78.2 m^3/ha/day - closely in agreement with the application rate of 80.4 m^3/ha/day
- Average irrigation water requirements tends to decrease as the total irrigated area increase - a sort of economy of scale

The distribution of the cultivated area according to the cropping patterns

Variable	Mean	Total area under a given crop (ha)	% of total cultivated area
Vegetable	1.16	129.5	44.5
Date palms	0.86	96.1	33.0
Alfalfa	0.16	18.3	6.3
Fruit crops	0.24	27.2	9.3
Ornamental	0.02	2.4	0.8
Poultry	0.02	2.4	0.8
Livestock	0.13	15.3	5.3
Total		291.2	100

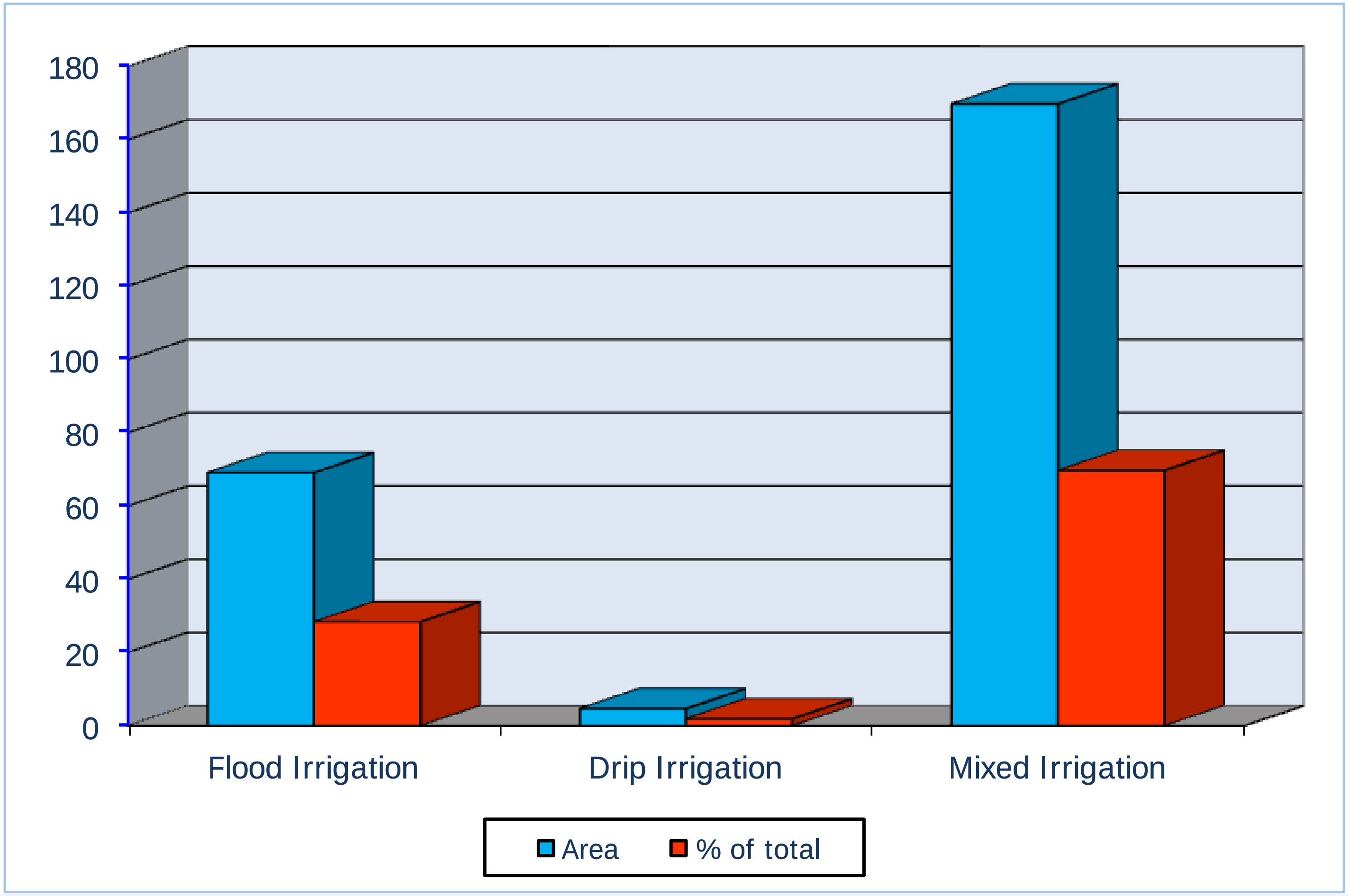
Areas under different crop patterns (ha) and their percentage distribution



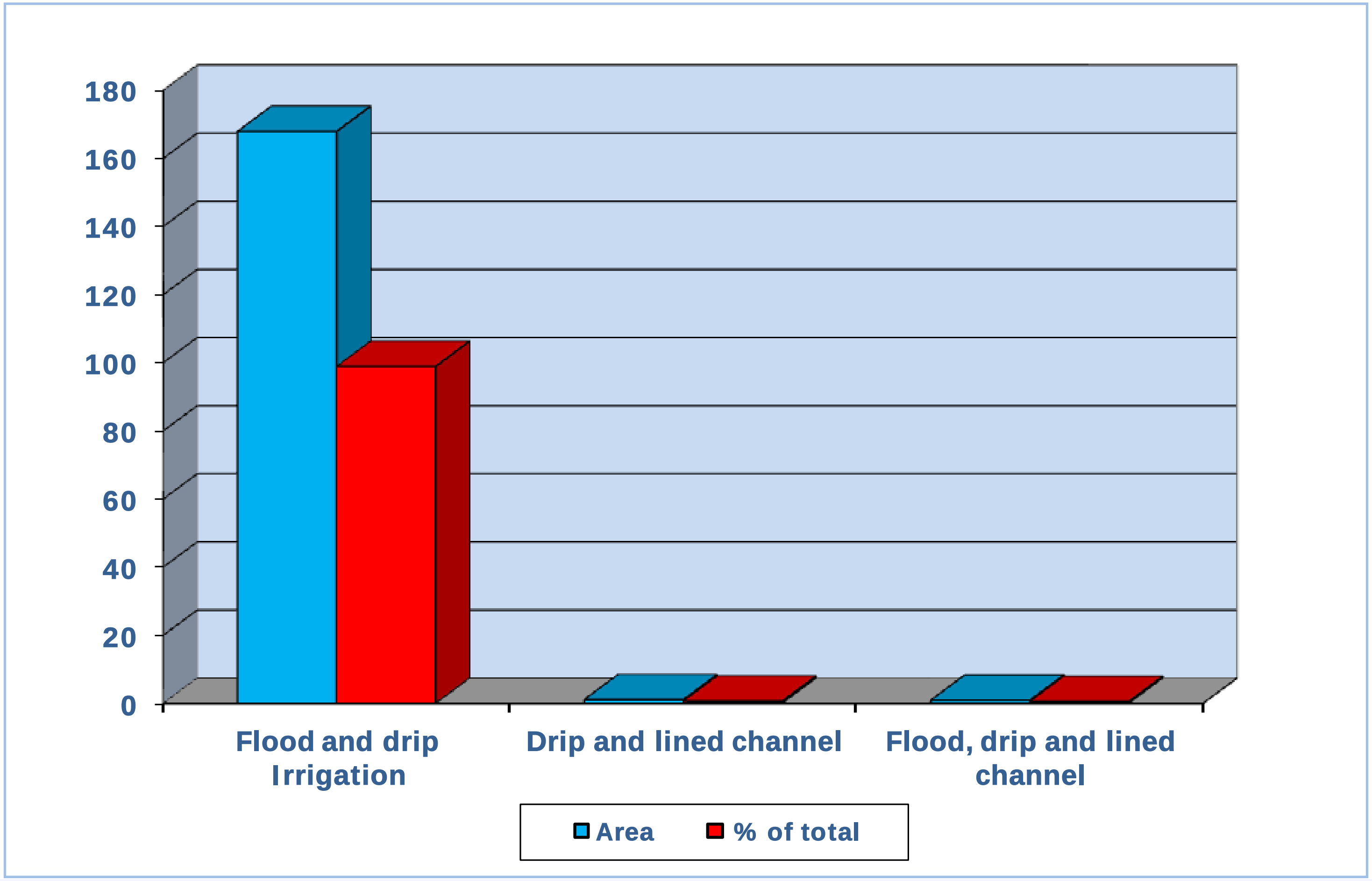
Distribution of areas under different methods of irrigation and their percentages of total irrigated area

Method of irrigation	Area under particular method of irrigation (ha)	% of total irrigated area
Flood irrigation	69.1	28.4
Drip irrigation	4.7	1.9
Mixed irrigation	169.8	69.7
Total	243.6	100.0
Areas under different types of mixed irrigation and their percentage of total		
• Flood and drip irrigation	167.9	98.9
• Drip irrigation and lined channels	1.0	0.6
• Flood, drip, and lined channels irrigation	0.86	0.5
Total area under mixed irrigation	169.8	100.0

Areas under different methods of irrigation (ha) and their percentage distribution



Areas under different types of mixed irrigation (ha) and their percentages of total



6. Model Estimation

- Average monthly agriculture water use as a dependent variable was regressed against a set of potential independent variables
- Empirical results were statistically disappointing
- The Lack of potential explanatory variables limits the ability to perform meaningful multiple regression analysis
- The equations of best statistical fits were represented by bivariate log-linear models - Explain 50% of the variation in agriculture water use

Derived log-linear demand functions for agriculture water use

Model	Regression equation	*F*- Statistics	Adjusted R^2
Model 1	$lnQ = 7.720 + 0.633lnX_1 + \varepsilon$ (56.115) (15.594) (0.000) (0.000) (0.138) (0.113)	31.293 (0.000)	0.244 $R = 0.502$
Model 2	$lnQ = 7.756 + 0.670lnX_1 + \varepsilon$ (58.389) (5.594) (0.000) (0.000) (0.133) (0.121)	30.868 (0.000)	0.241 $R = 0.499$

Notes: In Model 1, lnQ is the natural logarithm of the average monthly consumption in m^3 per month, lnX_1 is the natural logarithm of gross area under cultivation in hectare, and ε is the error term. In Model 2, lnQ is as defined earlier, and lnX_1 is the natural logarithm of gross area under irrigation in hectare, and ε is the error term. *t*- statistics, *p*-values, and standard error of estimates are, respectively, in parentheses beneath the coefficients.

The Effects of the Dummy Variables on Agriculture Water Use

- Dummy Irrigation Methods

- Statistically insignificant but had the expected signs.
- Empirical results suggest that both water efficient and traditional irrigation methods influence water demand.
- Coefficients were highly affected by the dominance of mixed irrigation method - difficult to isolate individual effects of each coefficient.

- Dummy Crop Patterns

- Identified as having serial correlations – individual effects probably masked by the dominance of inter-cropping farming practice.

- Coefficient of dummy date palm had the expected negative sign, but was insignificant at the 5% level.

- The dummies measuring vegetables and alfalfa crops were statistically significant - both were indicative of higher consumption.

Demand functions for dummy crop patterns measuring alfalfa and vegetable crops

$$\ln Q = 7.945 + 0.585\ln X_1 + 0.816\ln X_2 + \varepsilon$$

	$\ln Q$ constant	$\ln X_1$	$\ln X_2$
	(78.615)	(4.729)	(2.563)
	(0.000)	(0.000)	(0.012)
	(0.101)	(0.124)	(0.319)

Adjusted R^2 0.245   *F*-Statistic 16.25 (0.000)   Durbin-Watson Statistics 2.395

where, lnQ is the natural logarithm of the average monthly consumption in m^3 per month, $\ln X_1$ and $\ln X_2$ are the natural logarithms of the dummy variables measuring areas under vegetable and alfalfa crops in hectares, respectively, and ε refers to the error term.

The Effects of the Seasonal Variability

- Explored by developing separate summer and winter demand functions - Climate factors not considered
- Empirical evidence suggests that summer and winter demand do not vary greatly – cropping density
- Double log transformed functions produced more reliable statistical fits

Estimation results for summer and winter agriculture water demand

Model	Regression equation	F-Statistics	Adjusted R^2
Summer	$\ln Q_s = 7.881 + 0.541 \ln X_s + \varepsilon$ (50.014) (4.177) (0.000) (0.000) (0.158) (0.130)	17.451 (0.000)	0.171 R = 0.425
Winter	$\ln Q_w = 7.568 + 0.626 \ln X_w + \varepsilon$ (42.822) (4.309) (0.000) (0.000) (0.177) (0.145)	18.568 (0.000)	0.180 R = 0.436

Notes: $\ln Q_s$ and $\ln Q_w$ are natural logarithms of the average monthly water uses in summer and winter, respectively, in m^3 per month. $\ln x_s$ and $\ln x_w$ are the natural logarithms of gross areas under cultivation in summer and winter, respectively, in hectares. ε is the error term. Figures in parentheses under each coefficient are, respectively, the *t*-statistics, *p*-values, and standard error of estimates.

7. Conclusions and Policy Implications

- This study offers valuable data on a number of farm and irrigation variables
- Failure in developing more reliable multiple regression analysis is most likely due to the lack of good explanatory variables – This study is part of a broad supply – demand study
- This result may also support the contention that linear programming techniques are more effective in modeling agricultural water demand
- The models of best statistical fits are represented by bivariate log-linear functions. Variances are almost 50%

- Analysis of our data did not capture an appreciable seasonal differences in the irrigation water demand

- This research opens avenues for further research on farm-level water demand, incorporating more explanatory variables such as crop production, climatic factors, agricultural inputs and outputs, size of workforce per farm unit, .. etc, with perhaps larger sample sizes

- Much further work is needed to adequately address the complexity of this topic

- This endeavor highlights the importance of establishing and implementing effective agricultural policies and strategies to restore and improve the agriculture sector in Bahrain

Thank You