Estimation of Industrial Water Demand: Empirical Evidence from Bahrain

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Presentation Outline

1. The Objectives
2. Industry and Industrial Water Use
3. Data and Research Methodology
4. Statistical Results
5. Models Specification and Development
6. Conclusions and Recommendations

1. The Objectives

- Identifying and analysing factors that influence industrial water use
- Exploring the feasibility of developing water demand functions for industry

2. Industry and Industrial Water Use

- Until late 1930s – Pearl fishing and agriculture - discovery of oil in 1932 – transformed the economy to oil- based
- Mid 1970s – diversifying the economic base – enhancing manufacturing and banking and services
- Manufacturing – dominated by aluminium, aluminium, related products and petrochemicals - classified into 2-digits nine SIC Categories
- Manufacturing – contribution to GDP 15.05% at current prices (2012)
- Manufacturing activities organised in a number of industrial estates

The industrial estates and their total areas as of 2012

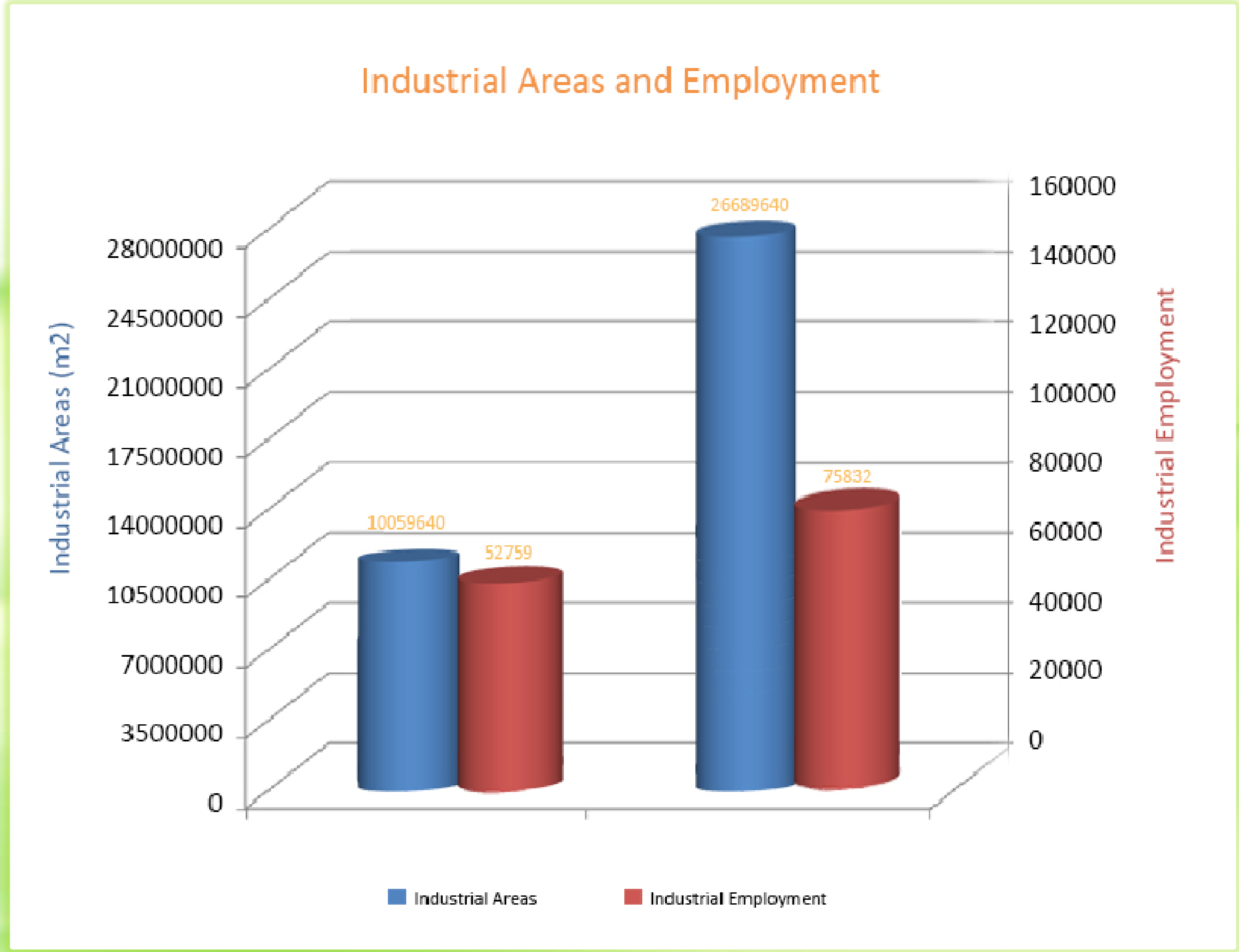
Industrial estate	Total area (m^2)	Percentage of total area (%)
North Sitra	1,770,000	8.0
Mina Sulman	730,000	3.3
Maameer	850,000	3.8
South Alba	4,316,111	19.5
North Refinery	360,000	1.6
Sitra Roundabout	120,000	0.5
Hafeera	2,413,529	10.9
Southwestern Hidd	8,880,000	40.0
Bahrain Investment Wharf	1,250,000	5.6
Bahrain International Investment Area	1,500,000	6.8
Total*	22,189,640	100.0

Source: Ministry of Commerce and Industry.* Total not include areas outside the I industrial estates.

Industrial Water Use – Basic Facts

- Sources of water use
  - self-supplied groundwater
  - blended water supply (public)
  - own-site seawater desalination
  - purchase from private sources
- Tendency towards using publicly supplied water – quality and reliability consideration
- Re-cycling not common practice – only in large water-intensive industries
- Do not pay a discharge (polluter) charge - effluent quality control normally observed

- Users of blended water are charged according to a separate block within the domestic increasing block tariff
- Most self-supplied wells are metered – industrial users do not pay for their volumetric use
- Accounts for a small share of total water use 4 - 8%
- Industrial water use shown an increasing trend over the last two decades - Increase in the industrial activities



Industrial Areas and Employment
Industrial Areas (m2)
28000000
24500000
21000000
17500000
14000000
10500000
7000000
3500000
0
Industrial Employment
160000
140000
120000
100000
80000
60000
40000
20000
0
10059640
52759
26689640
75832
Industrial Areas
Industrial Employment

Industrial water use and their percentages of total water use 2000 – 2012

Year	Industrial water use (Mm^3)	Total water use (Mm^3)	Percentage of total (%)
2000	18.1	366.6	**4.9**
2001	18.0	341.2	**5.3**
2002	19.1	352.7	**5.4**
2003	20.3	360.7	**5.6**
2004	22.4	359.7	**6.2**
2005	20.2	341.5	**5.9**
2006	21.2	364.6	**5.8**
2007	26.4	370.1	**7.1**
2008	26.8	401.4	**6.7**
2009	29.2	417.3	**7.0**
2010	29.1	429.8	**6.8**
2011	29.2	435.7	**6.7**
2012	31.1	425.4	**7.3**

3. Data and Research Methodology

- Data from a sample of a country-wide cross-sectional survey
- A set of demand determinants were hypothesised to influence industrial water use
- Sampling frame – Industrial Register (355 firms reduced to 305)
- Unable to obtain probability sample
  - traditional sampling approach
  - step-sampling approach

- Representative sample of 137 industrial firms
  - all types of industrial activities
  - all levels of manufacturing
- Sample data represents
  - 45% of the modified sampling frame
  - 39% of the total workforce
  - 59.4% of total water use in the base year
  - 65% of total factory floor area
- 160 questionnaire distributed - Rate of usable returns 90.5%

4. Statistical Results

Summary statistics of the key variables for industrial water use

Variable	Mean	Median	Min.	Max.	Std. deviation
Average water consumption (m^3/day)	315.1	25.5	0.7	13909.1	1306.8
Production level (tonnes/day)	1012.3	63.4	0.20	39747.0	4280.0
Factory floor area (m^2)	50252.3	6226.5	93.0	1950767	201749.9
Number of Employees	165.7	62.5	4.0	2600	348.5

Average water uses by internal type of use in manufacturing based on the sample data

Activity	Average volume of use (m^3 /day)	% of total
Production	265.49	84.3
Staff hygiene	35.11	11.1
Other purposes	14.47	4.6
Average consumption	315.07	100

Note: re-cycling factor was not considered in these calculations. Other uses include landscaping, floor washing, car washing, etc.

Comparison of macro- and micro-components analyses results of consumption values for key industrial variables

Variable	Macro-component analysis	Micro-component analysis
Average per employee water use (litres per employee per day - lped)	1486	2775
Average water use per factory floor area (m^3/m^2 of factory floor)	1.948	2.288
Average water use per factory floor area (m^3/day/m^2 of factory floor)	0.00533	0.00626
Average water use per unit of output (m^3/tonne)	---	0.536

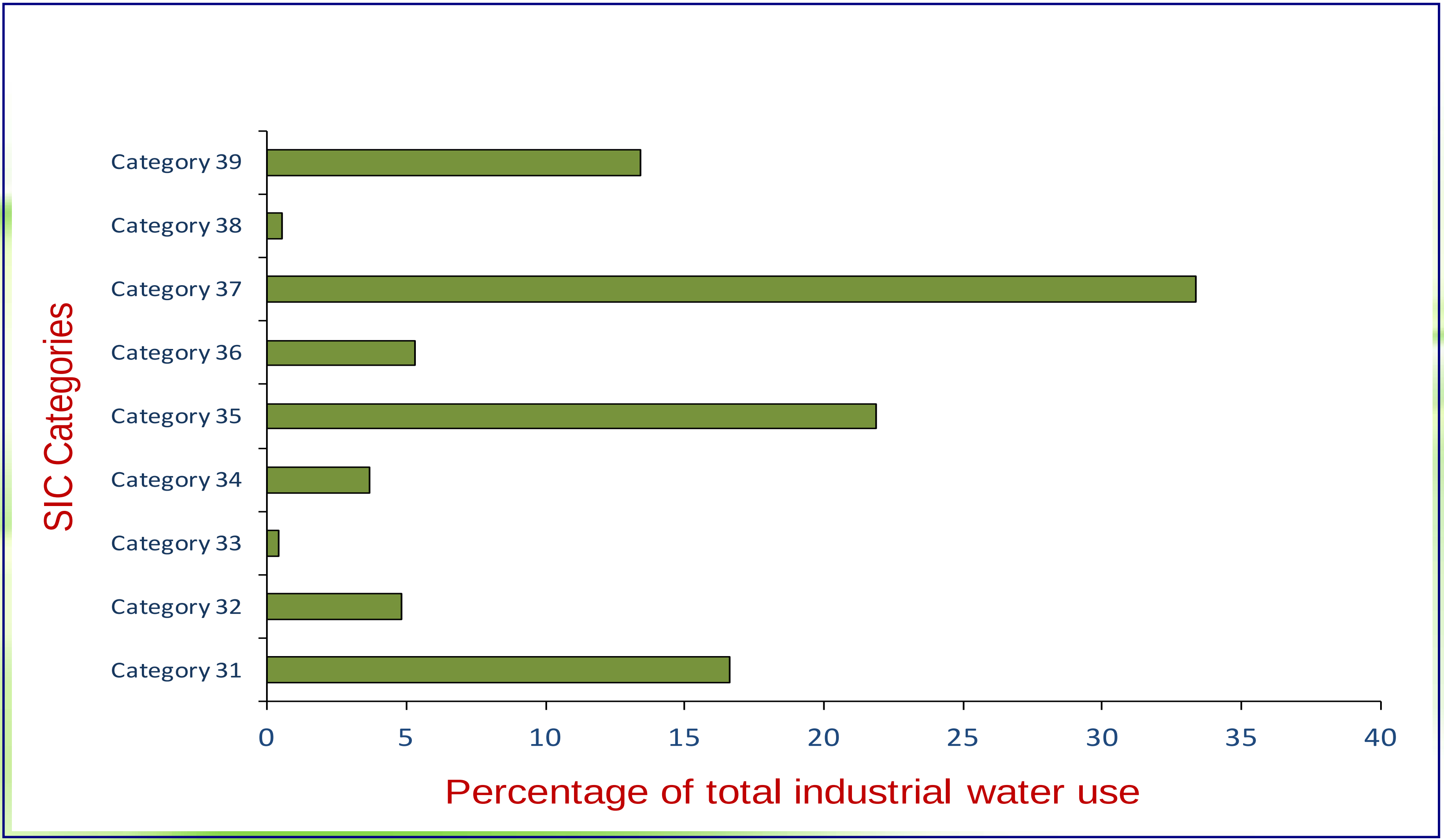
Notes: Per employee and per unit of output water uses are calculated based on 250 working days. (---) indicates that data were not made available for possible conversion to consumption value.

Disaggregation of sample data with reference to the Standard Industrial Classification (SIC) Categories and their key consumption values

SIC Categories	Industrial activity	Average Consumption m^3/day	Per employee water use (lped)	Water use per unit of output (m^3/tonne/day)	Water use per factory floor area m^3/m^2 of factory floor area
Category No. 31	Manufacture of food, beverages and tobacco	463.4	8197	1.08	0.036
Category No. 32	Textile wearing apparel & leather industries	133.4	221	9.52	0.015
Category No. 33	Manufacture of wood and wood products including furniture	11.8	103	7.9	0.0021
Category No. 34	Manufacture of paper and paper products, printing and publishing	103.8	1753	7.6	0.0054
Category No. 35	Manufacture of chemicals, and of chemical, petroleum, coal, rubber and plastic products	610.1	4032	0.33	0.0069
Category No. 36	Manufacture of non-metallic products, except products of petroleum and coal	147.0	1569	0.13	0.0048
Category No. 37	Basic metal industries	930.3	1478	0.31	0.0042
Category No. 38	Manufacture of fabricated metal products, machinery and equipment	12.5	134	0.35	0.0007
Category No. 39	Other manufacturing industries	372.1	723	---	0.002

A dash indicates missing value.

Percentage of industrial water use by SIC categories of users



5. Models Specifications and Development

- Dependent variable average industrial water use in m^3/day
  - cross tabulation
  - regressed against a set of potential explanatory variables
- Water price – quantity relationship was not considered – insufficient reliable data
- The use of production level as surrogate for price was unsuccessful
- Both linear and log-linear functions were tested
  - log-linear performed better in terms of goodness-of-fits
  - minimise multicollinearity effects
  - improve the assumptions tests

Derived log-linear demand estimating equations for industrial water use

Models	Regression equations	df	*F*-Statistics	Adjusted R^2	Std. error of the estimate	Durbin-Watson statistic	Average Tolera-nce	Aver-age VIF
Model 1	$\ln Q = 0.498 + 0.549\ln X_1 + 0.227\ln X_2 + \varepsilon$ (1.062) (10.750) (2.104) (0.291) (0.000) (0.038) (0.469) (0.051) (0.108)	2	69.588 (0.000)	0.583	1.321	2.025	0.941	1.063
Model 2	$\ln Q = -3.206 + 0.411\ln X_1 + 0.545\ln X_2 + \varepsilon$ (-3.790) (2.757) (5.224) (0.000) (0.007) (0.000) (0.846) (0.149) (0.104)	2	33.137 (0.000)	0.359	1.633	1.992	0.746	1.341

In **model 1**: lnQ (dependent variable) is the natural logarithm of the average consumption in m^3 per day, $\ln X_1$ is the natural logarithm of the production level in tonnes per day, $\ln X_2$ is the natural logarithm of the number of employees, and ε is the error term. In **model 2**: lnQ is as defined before, $\ln X_1$ is the natural logarithm of the number of employees, and $\ln X_2$ is the natural logarithm of the factory floor area in m^2, and ε is the error term.

Figures in parentheses under each coefficient are t-statistics, *p*-values, and standard error of estimates, respectively. Figures in parentheses under the *F*-Statistic values are the significance of *F*-test.

Influence of dummy variables on average industrial water use

Dummy connection to sewer

- model 1 insignificant
- model 2 significant at the 0.05 level (R^2 0.483)
- had unexpected negative sign – reflect local condition/ consistent with the results from our municipal survey
- Basic equation: <u>ln*Q* = 4.180 - 0.982 DUMSWER</u> (R 0.235)
- industrial firms connected to sewer use less water by 26%

Dummy water re-cycling

- statistically insignificant – had unexpected positive sign
- makes sense - dominated by water intensive industries/ main users of re-cycling systems
- 12% of firms sampled have recycling systems – 26% of total use of sample data – 63% in one firm (GPIC)
- Basic equation: $\ln Q = \underline{3.420 + 1.835\ \mathrm{DUMREC}}$ (R 0.288)
- Industrial firms having recycling system use more water by 33%

Dummy variable water source

- statistically significant
- singularity problems with the dummy use of desalination
- use of desalination gives better statistical fits/significant at better than 0.001 level/had the expected positive sign
- Basic equation: $\underline{\ln Q = 2.869 + 2.457\ \text{DUMDES}}$ (R 0.549)
- self-supplied firms with desalination plants use more water by 73%

Estimation results when dummy source of supply/use of desalination is added to the specification Model 1

$$\ln Q = -0.0624 + 0.428 \ln X_1 + 0.400 \ln X_2 + 1.542\ \text{DUMSRCE}$$
$$\quad (-0.138) \quad (7.770) \quad (3.717) \quad (4.213)$$

Adjusted R^2 0.645, F-Statistic 60.402, Durbin-Watson Statistic 2.275

where ln$Q$ is the daily average industrial water use, m^3 per day, X_1 *and* X_2 are as defined before in Model 1 and DUMSRCE is the water source variable (Two sets of coding (1) coded"1" for the self-supplied firms, and "0" for publicly-supplied firms and/or those who purchase water from outside sources, and (2) dummy desalination plant –coded "1" for firms having an on-site desalination plant, and "0" otherwise). The numbers in parentheses are t-statistic and indicate significance at the 0.001 probability level.

Estimation results when dummy source of supply/use of desalination is added to the specification Model 2

$$\ln Q = -3.263 + 0.546 \ln X_1 + 0.446 \ln X_2 + 2.319 \text{ DUMSRCE}$$
$$(-4.493) \quad (4.204) \qquad (4.904) \qquad (6.427)$$

Adjusted R^2 0.527, F-Statistic 43.738, Durbin-Watson Statistic 2.006

where ln$Q$ is the daily average industrial water use, m^3 per day, X_1 *and* X_2 are as defined before in Model 2, and DUMSRCE is the water source variable (Two sets of coding (1) coded"1" for the self-supplied firms, and "0" for publicly-supplied firms and/or those who purchase water from outside sources, and (2) dummy desalination plant –coded "1" for firms having an on-site desalination plant, and "0" otherwise). The numbers in parentheses are *t*-statistic and indicate significance at the 0.001 probability level.

Estimation results with dummy variable number of shifts

$$\ln Q = 2.781 + 1.148DUMSHFT2 + 1.913DUMSHFT3 + 3.280DUMSHFT4$$

(11.511)	(2.830)	(4.234)	(4.389)
(0.000)	(0.005)	(0.000)	(0.000)
	(0.406)	(0.452)	(0.747)
	(0.244)	(0.364)	(0.365)

R^2 0.215, standard error of estimate 1.8715, Durbin-Watson Statistic 1.769

Where lnQ is the natural logarithm of the daily average water use in m^3, and DUMSHFT2, DUMSHFT3, and DUMSHFT4 are the dummy variables representing firms working on respective shift bases. Number of employee per shift assumed to be constant. Figures in parentheses beneath each coefficient are, *t*-statistics, *p*-value, standard error of estimate, and standardised *B*eta coefficients, respectively.

Coefficient interpretation: Industrial firms working on two-shift bases use more water by 27% than those working on one-shift bases (reference group); firms working on three and four shift-bases use more water by 44%.

Estimation results with number of persons employed as a continuous variable for each significant SIC Category

The basic equation without the dummy variable designating industrial categories:

$$\ln Q = 1.611 + 0.502 \ln X_1$$

$$(2.632) \quad (3.624)$$

$$(0.10) \quad (0.000)$$

R 0.313, and standard error of estimate 1.878

where Q = average daily industrial water use, m^3 per day, and X_1 = the number of employees. Figures in parentheses beneath the regression coefficients are the *t*-statistics and *p*-values, respectively.

Multiple regression of average industrial water use, number of persons employed and SIC categories

Variable	Regression Coefficient	Significance (p-values)	Number of establishments
Constant	2.002	0.001	---
ln X	0.495	0.000	---
SIC 31	2.204	0.000	16
SIC 33	-1.913	0.026	3
SIC 34	-1.533	0.025	5
SIC 35	-0.927	0.009	27
SIC 38	-1.838	0.000	22

SIC Categories 32, 36, and 37 are not significant.

Derived demand function for industrial category SIC 38 with the number of persons employed as a continuous variable

$$\ln Q = 2.002 + 0.495 \ln X - 1.838 \text{ (coefficient of SIC 38)}$$

lnQ is the natural logarithm of the daily average water use, and lnX is the natural logarithm of the number of person employed.

6. Conclusions and Recommendations

- A country-wide cross - sectional survey was conducted to investigate the water demand characteristics in industry, and to explore the possibility of developing appropriate demand functions

- Our analysis produced important figures on key industrial consumption indicators, both on the macro- and micro-component levels

- The empirical evidence suggested that average industrial water use is positively responsive to changes in the variables factory floor area, number of employee, and output level. Available data on water price were insufficient to investigate price-quantity relationship

- The log-linear demand models exhibited statistical superiority over the linear functions. The model of best fit explains 59% of the variation in the industrial water use
- The significant effects of the dummy variable water source on the derived demand functions highlight the importance of this factor on the water use for industry in Bahrain
- A key finding is that the number of persons employed and the SIC Categories are important determinants of industrial water use. Developing of water use guidelines based on these factors is therefore important for improving management of water demand

THANK YOU