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Economic Analysis of Residential, Commercial, and Industrial Uses of Water in Sri Lanka

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Abstract: *The aim of this study is to provide an economic analysis of urban water use with a view to enhance the understanding of the factors influencing urban water demand and to estimate price elasticities of residential, commercial, and industrial water demands in Sri Lanka. Lack of research in the Sri Lanka context of this area and the need for understanding the price elasticity of demand for urban water for effective implementation of the new water-demand management policy formulated by the Government of Sri Lanka in early 2000 were important motivations for this study. Separate water-demand functions for each of the major sectors were estimated, using monthly time series for 60 months from January 1994 to December 1998. In general, the price is found to have a significant effect on water demand, and this effect is much higher for the industrial sector than for the residential and commercial sectors. In addition, real income, number of connections (population), and weather variables are found to be important determinants of urban water demand. Estimated price elasticities are -0.18, -0.17, and -1.34 for the residential, commercial, and industrial water demands, respectively. The study concludes that while the price will be an important tool in influencing demand, other measures such as public education and information/awareness will be necessary to achieve desired reductions in water consumption, especially in the less-responsive residential and commercial sectors.*

Keywords: *Urban water use, economics, demand elasticity, Sri Lanka.*

Introduction

Urban and regional demand for freshwater in Sri Lanka has grown significantly over the last decade. (A region consists of both urban and rural areas. For administrative purposes, the National Water Supply and Drainage Board of Sri Lanka has divided the country into five main regions: Greater Colombo, Southern region, Western region, Central region, and Northeast region.) Growth in water demand has been particularly high since 1994. The total water consumption from piped water supplies has increased from 120 million cubic meters (Mm^3) in 1994 to 191 Mm^3 in 1998 (Table 1). Population growth, rapid urbanization, and overall expansion in economic activities are major causal factors underlying such increases in water consumption. Residential water use estimated at 98.13 Mm^3 in 1998, followed by commercial and industrial uses, accounts for the largest share of total urban water consumption in Sri Lanka. (Non-revenue water is the quatity of water unbilled for the total production. This includes leaks from transmission, distribution mains, and other structures in the system, illegal connections, metering errors, and consumption in wayside and garden taps). Disaggregated data (Table 1) indicate that water consumption in the residential, commercial, and industrial sectors has increased by over 34, 27, and 37 percent, respectively, over the period 1994 to 1998. However, the average water consumption per connection shows a slight fluctuation over the same period for the residential and commercial sectors, while it shows a declining trend for the industrial sector. This may be partly attributed to the increasing use of alternative sources of water, as will be discussed later in this paper.

While the total population in Sri Lanka is projected to stabilize at 23 million by 2025, the urban population is expected to increase from the current 5.6 million to 15 million, i.e., from 30 percent to 60 percent (SLNWP, 2000). Similarly, the economy is likely to continue to grow, with significant growth expected in the commercial, services, and industrial sectors over the coming decades. As a result, pressure on available water supplies and infrastructure will continue to increase. While in aggregate terms Sri Lanka has plentiful water resources, there is a high degree of variation in the availability of water seasonally and regionally. Nearly two-thirds of the country gets less than 1,500 mm of rainfall in a year and almost all of it comes during the short monsoon season from October to January, with 51.1 percent of this escaping to the sea (SLNWP, 2000). There are a number of warning signs pointing to increasing water resources problems in the country. Competition and water shortages will continue to increase as a result of highly variable rainfall and growing demand for water across sectors. Irrigation continues to

Table 1. Annual Total and Per Connection Water Consumption in Sri Lanka by Sector, 1994 to 1998

Year	*Residential Total Consumption (million m³)*	*Consumption Per Connection* (m³)*	*Commercial Total Consumption (million m³)*	*Consumption Per Connection* (m³)*	*Industrial Total Consumption (million m³)*	*Consumption Per Connection* (m³)*	*All Uses** (million m³)*
1994	64.29	22.79	13.00	54.76	2.02	353.02	120
1995	73.55	23.54	14.90	58.18	2.68	338.20	147
1996	80.70	23.18	15.09	54.34	2.90	310.61	152
1997	88.41	22.97	16.00	52.89	2.85	276.09	171
1998	98.13	22.75	17.77	54.11	3.24	291.00	191

*Indicates average monthly consumption per connection.
**All uses include residential, commercial, industrial, government, institutional, and religious and non-revenue water.

remain a dominant water-using sector accounting for over 90 percent of the total freshwater withdrawn through artificial means. However, part of this water is used for domestic, environmental (absorbed by the natural vegetation and wetlands), and other purposes, or is returned as drainage or groundwater. Industrial and commercial sector water demands are mainly met from piped water supply, supplemented with pumping from surface and groundwater sources. Household water demands are met from piped water supply as well as domestics wells. Aggregate demand for water in Sri Lanka is expected to continue to increase due to population growth, rapid urbanization, and expansion in economic activities. While developing additional water resources to meet growing demand in the future would be essential, the scope for supply expansion would be limited as new projects tend to be less-technically feasible and less economically viable (GOSL, 2000).

Concerned with increasing costs of developing additional water supplies and infrastructure and the existence of inefficiencies in the system, relevant public authorities are taking initiatives to adopt conservation and water use efficiency measures, a move towards demand management. The Government of Sri Lanka has formulated a new National Water Resources Policy, approved by the Cabinet of Ministers on March 28, 2000, to address the growing problems in the water resources of the country. The objective of this new policy is "to ensure the use of water resources in an effective, efficient, equitable manner, consistent with the social, economic, and environmental needs of present and future generations." Water resources demand management is the central component of the new policy. The objective of this component is to "promote the efficient use of water resources and to maximize the value of the resource to society" (GOSL, 2000). The new initiative emphasizes the need and importance of using economic instruments, coupled with other strategies such as metering, education and awareness, and investment for leakage prevention, in managing water resources. Appropriate pricing policies are believed to be the key to improve water use efficiency and raise sufficient revenues for better services and improved operation and maintenance (O&M) of the supply system. In addition, education and awareness programs on water saving technologies and recycling procedures and investments and incentives for water conservations and regulatory measures are being considered as important elements of demand management policy (GOSL, 2000).

Water pricing will work as a demand management instrument to the extent that connections are metered, and that people actually pay for services, and that they have incentives to pay. In Sri Lanka, almost all the urban connections are metered except stand posts for public usage. However, a considerable percentage of total water produced is accounted for as non-revenue water (NRW) due to leaks from transmission, distribution mains, and other structures in the system, illegal connections, metering errors, and consumption in wayside and garden taps. NRW accounted for 48.6 percent in 1994 and gradually decreased to 35.8 percent in 1999 (NWSDB, 2000). There is a proper billing system in place, and there is a penalty of service cut-off if water bills are not paid. Overall, the collection efficiency (the actual total collection as a ratio of total revenue billed averaged over the year) of the metered connections is fairly high, averaging around 90 percent during 1998 to 1999.

Designing an appropriate pricing policy and efficient planning and management of urban water supply systems, however, require a thorough understanding of the determinants of water demand. Until now, no serious attention has been given in Sri Lanka to quantify water-demand relationships. Generally, multiplying forecast population changes with per capita water consumption with the implicit assumption that economic and behavioral characteristics remain stable makes water-use forecasts. This assumption is quite unrealistic, and to be able to make reasonably reliable forecasts, the influence of the price and other demand-related variables must be determined and included in forecasting procedures. The quantification of urban water-demand relationships will be useful to the NWSDB (National Water Supply and Drainage Board) and concerned policy makers to predict consumption response to changes in water pricing policy and it will provide a basis for water consumption forecasts in the country. This paper attempts to analyze demand for urban water by user class. The principal interest here is to quantify consumers' response to changes in the water price and to provide insights into the potential role of prices as a demand-management tool. This is measured by estimating the price elasticity of demand, defined as the percentage change in quantity demanded in response to a one percent change in the price of water.

The aim in this study is to provide an economic analysis of urban water use with a view to enhance the understanding of the factors influencing urban-water demand. More specifically, the objective is to estimate price elasticities of demand for water for the residential, commercial, and industrial sectors of Sri Lanka.

Water Supply and Pricing in Sri Lanka

The NWSDB, established in 1975, is the principal agency for supplying piped water in Sri Lanka. It is responsible for planning, design, construction, and operation and maintenance (O&M) of all rural and urban water supply and sewage schemes in the country. Presently, the Board operates 283 water-supply schemes throughout the country, and billing, collection, and other operations and policies are implemented through its regional offices. Water consumers are charged a fee based on volumetric pricing, and the Board administers the same pricing policy across the country. The main objectives of the water pricing policy are: (1) to generate revenues to cover O&M costs; and (2) to use pricing as a demand-management instrument, to discourage wasteful use of water. The pricing system followed consists of two types of charges: (1) fixed or basic charges; and (2) variable or consumption charges. For the residential sector, the NWSDB applies consumption charges using increasing block-rate pricing that uses seven blocks. Consumers are billed on a monthly basis. Under the increasing block-rate pricing system, monthly bills of consumers using water under different blocks may be mathematically expressed as:

$$
\begin{aligned}
B_1 &= [MP_1 * Q] + F \quad \text{if } 0<Q\leq q_1 \\
B_2 &= [MP_2*(Q- q_1) + MP_1* q_1] + F \quad \text{if } q_1<Q\leq q_2 \\
B_3 &= [MP_3*(Q- q_2) + MP_2*(q_2- q_1) + MP_1* q_1] + F \quad \text{if } q_2<Q\leq q_3 \\
&\ldots \\
B_7 &= [MP_7*(Q- q_6) + MP_6*(q_6- q_5) + MP_5*(q_5- q_4) + MP_4*(q_4- q_3)\ MP_3*(q_3- q_2) + MP_2*(q_2- q_1) + MP_1* q_1] + F \quad \text{if } q_6\leq Q
\end{aligned} \tag{1}
$$

where B_i is monthly bill of customer using Q units of water; MP_i is the marginal price ($MP_7>MP_6>MP_5>MP_4>MP_3>MP_2>MP_1$); q_i is the break-point of the price schedule ($i=1–7$); and F is the monthly fixed charge. (Note: Under the new policy introduced in October 1997, a customer pays a fixed lump sum for the first 10 m^3, first block, regardless of the level of consumption within the block).

In 1998, the average monthly consumption of water in the households in the Greater Colombo area and in the regions amounted to 25.72 m^3 and 19.26 m^3, respectively, with a large majority of residential consumers coming under the second and third blocks.

A significant number of low-income residential consumers, particularly in the Colombo area, receive their water supplies free of charge or at highly subsidized rates from stand posts, which are generally unmetered. The government normally bears the cost of stand post supplies, and the consumers, therefore, have little or no incentive to save water. At present, the standpost water constitutes a significant part of the non-revenue water in urban areas. In 1999, total non-revenue water in Sri Lanka was estimated at 35.8 percent, which includes unaccounted-for-water (resulting from losses due to leaks in the distribution system, illegal connections, defective meters) and water consumption from standposts.

For nonresidential users, including industrial and commercial sectors, consumption charges are applied using fixed rates per cubic meter (P), and the consumer's monthly bill (B) is simply determined as:

$$B_I = [P_I * Q_I] + F_I \tag{2}$$

$$B_C = [P_C * Q_C] + F_C \tag{3}$$

where subscripts I and C represent industrial and commercial sectors, respectively, and F_I and F_C are monthly fixed charges in the respective sectors.

The NWSDB water rates over the last two decades are presented in Table 2. These rates have generally been higher for nonresidential users including commercial and industrial users than for residential consumers. However, there have been significant changes in rate schedules since the early 1990s. All consumer monthly fixed service charges were replaced in January 1993, with separate monthly service charges for residential and nonresidential consumers. From October 1997, the NWSDB has replaced the nonresidential fixed charge with a monthly charge, based on the diameter of the connection, and has abolished the separate residential fixed monthly charge by including it into the first block of the schedule. Residential consumers are charged a fixed rate for the first block regardless of the amount consumed, i.e., a person consuming 1 m^3 or 10 m^3 within the first block has to pay the same fixed amount. The first block rate changed from Rs. 0.60 per m^3 (plus a fixed service charge of Rs. 15) in January 1997 to a lump sum of Rs. 25 in October 1997 and Rs. 30 in March 1999. Are the first block consumers, who could be reasonably assumed to be low-income consumers, better off or worse off with this change? Certainly, they are worse off. Consider, for example, two consumers, one consuming 5 m^3 (low-income user) and the other 50 m^3 (high-income user). This change represents a 39 percent increase for the small consumer compared to only an 18 percent increase for

Table 2. Schedule of Water Charges in Sri Lanka, 1981 to 1999

	1981-1983	*Jan. 1984*	*April 1990*	*Jan. 1991*	*Aug. 1991*	*Jan. 1992*	*Jan. 1993*	*Jan. 1994*	*Jan. 1997*	*Oct. 1997*	*Jan. 1999*
					Service Charges						
All consumers (Rs)	0	0	5.00	5.00	5.00	5.00	-	-	-	-	-
Residential (Rs)	-	-	-	-	-	-	6.00	6.00	15.00	-	-
Nonresidential (Rs).	-	-	-	-	-	-	10.00	20.00	200.00	-	-
					Metered Rates (Rs/m^3) Residential						
0 - 10 m^3	0.20	0.20	Free	1.00	0.60	0.65	0.75	0.75	0.60	25.00*	30.00*
11 – 20 m^3	0.75	1.00	1.00	1.50	1.00	1.10	1.20	1.30	1.50	1.80	2.50
21 – 25 m^3	1.00	3.00	3.00	4.50	4.00	4.00	4.50	4.80	5.00	6.00	7.50
26 – 30 m^3	-	-	-	-	-	-	-	4.80	9.60	12.00	15.00
31 – 40 m^3	1.75	5.50	5.50	8.00	7.50	7.00	8.50	9.40	12.50	15.00	18.00
41 – 50 m^3	1.75	5.50	5.50	8.00	7.50	7.00	8.50	12.00	18.00	20.00	20.00
Over 50 m^3	1.75	5.50	11.00	19.50	19.50	20.00	25.00	25.00	32.50	35.00	35.00
					Nonresidential						
Commercial	2.75	5.50	11.00	19.50	19.50	20.00	21.00	22.00	25.00	25.00	27.50
Industrial	5.50	9.00	16.50	25.00	25.00	25.00	25.00	25.00	25.00	25.00	27.50

Source: NWSDB, Annual Report 1998 and 1999. Water charges are in nominal terms. *Indicates fixed rate per 10 m^3. Consumers are charged a fixed rate for the first block, regardless of the amount consumed, i.e., a person consuming 1 m^3 or 10 m^3 within the first block pays the same fixed amount.

the large consumer from January 1997 to October 1997. Similarly, change from October 1997 to March 1997 represents 20 percent increase for small consumers and 15 percent increase for large consumers.

Until October 1997, income equity among consumers appears to have been an important consideration in setting rate schedules, with a significantly lower rate in the initial block intended to subsidize low-income low-volume consumers. However, under the new policy, revenue raising (and gradual reduction of cross-sector subsidization) seems to be a dominant criterion in setting water charges. Since the price elasticity of demand could be expected to be very low for lower levels of consumption (initial block), the overall revenue could be easily increased by raising rates more for low-volume consumers than for high-volume consumers. This is how the NWSDB is attempting to increases its revenues. But this policy is likely to have some implications for income equity among consumers in the country.

Let us now briefly look at efficiency and equity implications of the new policy, with a focus on residential water use. Water in the premises of a household is used for several purposes including basic needs such as drinking, cooking, washing, etc., and other purposes such as swimming (in swimming pools), hobby gardening, etc. Water in the above uses may be classified as "necessity good" and "luxury good," respectively. Demand for water can be expected to be highly price-inelastic for certain basic levels of consumption, beyond which it becomes price-elastic as the "luxury" use begins. This is illustrated with the aid of Figure 1, where MB (marginal benefit) and MC (marginal cost) are demand and supply curves, respectively, for water use in the urban sector. The MB curve slopes down sharply up to point *a* reflecting the price inelastic nature of water used as a necessity good beyond which it becomes price-elastic. Assume MB and MC curves intersect at point *a*, which represents the welfare maximizing efficient point. Any deviation from this point would result in social cost or efficiency loss (or "deadweight loss"). Suppose the current water price is P_1, which

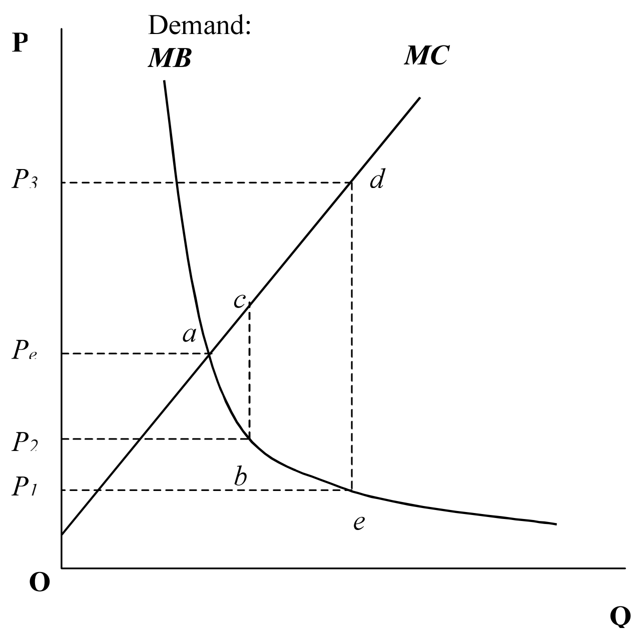

Figure 1. Marginal benefit and marginal cost curves for residential water use. Source: Yujiro Hayami, 2000.

is much lower than the equilibrium price P_e. The government provides a significant amount of subsidy represented by *de* to keep the price at P_1. In the present situation, there is a significant deadweight loss to the society, represented by area *ade*, caused by consumers using more water than they would do if they had to pay the marginal cost of water supply. This loss in efficiency is associated with some gain in consumer surplus represented by the area aP_eP_2b. However, high-volume consumers, rich people using water for luxurious purposes, are capturing a significant part of the gain in consumer surplus. Increasing the prices and reducing the subsidies can reduce the efficiency loss. A small increase in the price for high-volume consumers (in the price-elastic zone) will result in a significant reduction in efficiency loss. For example, if the price is increased from P_1 to P_2, the deadweight loss would be reduced from *ade* to only *acb,* indeed a significant gain in efficiency, and the gain in consumer surplus would reduce from aP_eP_1e to aP_eP_2e. Low-volume consumers – poor consumers using water for basic purposes, will capture a large part of this gain. In other words, the reduced gain in consumer surplus was that part of the total gain, which was being captured by high-volume consumers before the price change. Thus raising the price from P_1 to P_2 is justifiable on both efficiency and equity grounds. However, the price increases should be larger for high-volume consumers (higher blocks), where water consumption operates at the price-elastic zone, than for small consumers using water for basic needs.

Past Work

Literature

Numerous studies estimating demand relationships for urban water use are available in the literature on economics of water. These studies have used cross-sectional, mico/macro time series, or pooled data and have conducted analyses at aggregate or disaggregated levels by season, by type of use, or by user class. A wide variety of econometric models, ranging from a single equation to a system of simultaneous equations, have been employed by these studies. More recently, the contingent valuation approach has also been applied to analyze urban water demand. The studies prominent in the literature empirically investigating demand relationships include: Turnovsky (1969); Hanke (1970); Young (1973); Oh (1973); Danielson (1979); Grebenstein and Field (1979); Billings and Agthe (1980); Hanke and deMare (1982); Howe (1982); Babin et al. (1982); Jones and Morris (1984); Williams and Suh (1986); Deller et al. (1986); Moncur (1987); Thomas and Syme (1988); Renzetti (1990); Griffin and Chang (1991); Schneider and Whitlatch (1991); Neiswiadomy (1992); Stevens et al. (1992); Hewitt and Hanemann (1995). Malla and Gopalakrishnan (1997; 1999) have summarized literature on the residential, commercial, and industrial water demands providing a summary on the type of data and variables used, analytical techniques employed, and major findings and conclusions of most of the above-mentioned studies. One general conclusion from a review of the above studies is that demand for water is price-inelastic. The estimates of price elasticities, particularly from time series analyses, ranged from -0.03 to -0.65, -0.07 to -0.36, and -0.33 to -1.16 for the residential, commercial, and industrial sector demands, respectively.

Most of the available past studies are those that deal with urban water demand in the context of developed economies, principally from the US. There are only a very few studies dealing with economics of urban water in the developing economies. This important research area has largely been neglected in the past. To the best of the authors' knowledge, only two studies are available that investigate urban demand relationships in Sri Lanka.

The study by Chandrasena (1999) estimated demand functions for residential water use within the Kandy municipal limits using both primary cross-sectional data, collected though a survey of 58 households in June 1999, and the secondary time series monthly data for the period 1993 to 1999 (excluding data for 1996). The dependent variable used was the monthly household water consumption. Household income, household size (number of persons), and the Taylor-Nordin difference variable were used as explanatory variables in both cross-sectional and time series components of the study. The price variable used in the time series analysis was the marginal price of water (rather surprisingly, no price variable was used in the cross-sectional analysis). Equations specified in linear form were estimated using the Ordinary Least Squares (OLS) technique. In the cross-sectional analysis, the only significant coefficient was that of the difference variable (coefficients of income and household size were insignificant). The elasticity of the difference variable was 0.47. In the time-series analysis, coefficients of all the variables were significant with the expected signs, except for the income variable, which turned out to be negative. The marginal price elasticity of demand was estimated at -0.03, which is extremely low. Overall, the results of this study are confusing. The omission of the price variable, the key variable in the demand analysis, in the cross-sectional analysis has undermined the usefulness of the analysis.

The second available study, Jayasundara et al. (1999) estimated willingness to pay for improvements to the quality of drinking water, using the contingent valuation approach. The study used data from a survey of 140 households in two zones of Colombo and found that residents, on average, were willing to pay an additional Rs. 5.27 per m^3 if they were provided with reliable and safe drinking water. The elasticity of willingness to pay with respect to water consumption was estimated at -0.55. Furthermore, willingness to pay was positively related to the income of the consumers. Overall, given the nature and limited scope of this study, the results are of very little use in designing pricing policy or forecasting water consumption.

So far, no studies have been carried out on empirically investigating demand relationships in the Sri Lankan commercial and industrial sectors. The present study attempts to fill this gap by systematically analyzing the urban demand for water in Sri Lanka. The study is a part of IWMI's work on the valuation of multiple uses of water. The results of this study will enhance the understanding of the factors influencing the residential, commercial and industrial water demands, and can be useful to water policy makers in designing urban water-pricing policies and in forecasting urban water with considerable accuracy.

Issues in Water Demand Analysis

The specification and estimation of water demand functions have been highly controversial. This controversy originates from analytical complications arising from the block-rate pricing system, commonly followed for pricing water for residential use in most countries. Under this system, there is no single price and the quantity of water consumed and the price paid by each consumer during each time period depends upon the whole price schedule facing the consumer during that period. The controversy arises over the choice of the price variable, the key variable in demand analysis. Some past studies have adopted average price formulation, i.e., the total payments divided by the total quantity of water used. However, it has been correctly pointed out in some past studies that this formulation would implicitly use the quantity variable on both sides of the equation, introducing a simultaneity problem. Taylor (1975) suggested the use of the average price overall rate steps prior to the marginal step. Later, Nordin (1976) modified Taylor's approach and suggested the inclusion of the marginal price and a difference variable to represent the intra-marginal price structure in the specification. The difference variable is basically a difference between the consumer's actual bill and the amount if the entire bill was paid at the marginal price. It measures income effects of the intra-marginal price changes and may be considered a kind of subsidy or tax associated with increasing or decreasing block rates for consumers using water above the block break-points. In the case of the increasing block-rate system, the difference variable is an implicit subsidy because the consumer would be paying more if the entire quantity consumed is charged at a higher marginal price applicable to higher blocks. For a detailed discussion on the above formulation, see Billings and Agthe (1980); Griffin and Martin (1981); Howe (1982); Agthe et al. (1986). Some authors have extended the above approach by using instrumental price estimates. Jones and Morris (1984) specified two demand equations, one with the instrumental average price and the other with the instrumental estimates of the marginal price and associated difference variable. Jones and Morris (1984), however, concluded "instrumental estimation of price produces results not fundamentally different from simpler OLS approaches to demand estimation. In particular, average price procedures seem suitable for development within an applied context where data deficiencies rule out more exact demand specification."

Data and Methodology

General

This study uses monthly aggregate (country level) data from January 1994 to December 1998. The data on aggregate monthly water consumption, total number of active connections and monthly total water bills for each month for the residential, industrial, and commercial sectors were obtained from the monthly bulletin *Key Management Information* (NWSDB 1994–98). The NWSDB categorizes water users into 25 classes including residential, industrial, commercial, and schools, hospitals, religious institutions, the army, etc. However, the first three user classes constitute the major water-consuming sectors, and these were chosen for detailed analyses in this study.

The schedule of water price was obtained from the NWSDB's *Annual Report 1998*. As mentioned earlier, the NWSDB applies increasing block rates to its residential customers (from October 1997, residential customers pay a fixed lump sum for the first 10 m^3, regardless of the level of consumption within the block, and then as per block rate) and a fixed rate per cubic meter for its industrial and commercial water users (i.e. regardless of the amount consumed, industrial, and commercial entities using 10 m^3 or 100 m^3 pay the same fixed rate per cubic meter). Due to the non-availability of detailed block-wise monthly data on water consumption, the marginal price of water for the residential-sector analysis used was the block price corresponding to the average monthly water consumption per connection. For example, if the average monthly water consumption (the total water consumption in a month divided by the total active connections in that month) in a particular month fell in block three, the third block price was taken as the marginal price of water for that month. For industrial and commercial sectors, fixed prices per cubic meter of water as charged by the NWSDB were used in the analyses. The price variables were adjusted for inflation by using the Greater Colombo Consumer Price Index (for the residential sector prices) and the GDP Deflator (for the industrial and commercial sector prices). These indices were obtained from *Annual Report* 1999 of Sri Lanka's Central Bank. Since the published indices were available only on an annual basis, monthly indices were derived from annual values through interpolation on the assumption of constant growth.

Per capita or per household income data from the NWSDB's service areas were not available. Per capita GNP, obtained from the above annual report, was used as a proxy for consumer income. Monthly per capita income was derived from the annual GNP values through interpolation, using inter-year GNP growth rates. The data for employment in the industrial sector (comprising industries including salt, sugar, timber, paper, printing, drugs, petroleum, rubber, minerals, phosphate, and other public and private industries) were also obtained from the above annual report. Annual data were converted into monthly values through interpolation, using inter-year growth rates. The data on weather variables used in this study, average monthly rainfall and average monthly temperatures from nine observation stations (located in Colombo, Jaffna, Trincomalee, Hambantota, Ratnapura, Anuradhapura, Kandy, Diyatalawa, Bandarawela, and Nuwara Eliya), were obtained from *Statistical Abstracts* 1995 to 1999 (GOSL, 1995–1999). The mean of district averages for each month was used in the analyses.

Specification of Model

Demand for water, in general, is influenced by a variety of factors. These include the price of water, consumer income, population and its growth rate, level and type of economic activities in various sectors, and weather conditions. However, the purpose and the level of water use may differ across various water-using sectors. For example, the industrial and commercial sectors use water mainly as production input as opposed to the residential sector that uses water mainly as a direct consumption good. Therefore, it is important to analyze demand for water in high-use sectors separately. Based on the economic theory and results of the past studies conducted elsewhere, the residential demand for water in this study is modeled as a function of the price of water, consumer income, number of active water connections, rainfall, and temperature. Similarly, demand for water in the industrial and commercial sectors is modeled as a function of the price of water, industrial/commercial output/sales, number of active connections, rainfall and temperature.

The conceptual models for each of the three major water-using sectors are as follows:

Residential

$$W_R = f\,(P_R, D, I, C_R, R, T) \qquad (4)$$

where W_R is the average monthly water consumption in the residential sector; P_R is the price of residential water; D is the Taylor-Nordin's difference variable; I is the per capita income, C_R is the number of residential connections; R is the average monthly rainfall; and T is the average monthly temperature.

Commercial

$$W_C = f\,(P_C, O_C, C_C, R, T) \qquad (5)$$

where W_C is the average monthly water consumption in the commercial sector; P_C is the price of commercial water; O_C is the commercial sector output/sales; C_C is the number of commercial connections; R is the average monthly rainfall; and T is the average monthly temperature.

Industrial

$$W_I = f\,(P_I, O_I, C_I, R_I, T_I) \qquad (6)$$

where W_I is the average monthly water consumption in the industrial sector; P_I is the price of industrial water; O_I is the industrial sector output/sales; C_I is the number of industrial connections; R_I is the average monthly rainfall in industrial zones; and T_I is the average monthly temperature in industrial zones.

Estimation and Results

Based on the preliminary statistical analysis and consideration of data limitations for certain variables (particularly for commercial sector output/sales (O_C) and industrial connection (C_I), the following equations were chosen for estimation.

$$W_R = a_0 + a_1P_R + a_2D + a_3I + a_4 C_R + a_5R + a_6T + \hat{I}_{R;} \qquad (7)$$

$$W_C = g_0 + g_1P_C + g_2C_C + g_3R + g_4T + \hat{I}_C \qquad (8)$$

$$W_I = b_0 + b_1P_I + b_2E + b_3T + b_4R + \hat{I}_I \qquad (9)$$

where *a, b,* and *g* are parameters to be estimated; E is the number of employees in the industrial sector (used as a proxy for industrial output/sales); $\hat{I}_R$, $\hat{I}_I$, $\hat{I}_C$ are error terms in the respective equations. All other variables are as defined above.

Since there was no *a priori* basis for selecting the functional forms, the equations were specified using both linear and log-log forms. The equations were estimated using OLS and were tested for econometric problems commonly suspected in time series, such as multi-collinearity and autocorrelation. The Variance Inflation Factor (VIF) test is a commonly used for determining the strength of multi-collinearity problem in the data. $VIF_I = 1/(1\text{-}R^2)$ where R^2 is the coefficient of determination in the regression of one independent variable on the remaining independent variables. The higher the value of VIF, ie., higher than five, the greater the magnitude of multi-collinearity. The VIF test indicated the absence of any severe problem of multi-collinearity. However, the Durbin-Watson test statistic provided evidence of first-order autocorrelation in the industrial and commercial sector demand equations, which were corrected using the Generalized Least Square. The difference variable, D, was removed from the residential demand equation after a preliminary analysis showed its coefficient to be statistically insignificant and the nature of its results to be somewhat dubious. The results of the estimated linear and log-log equations for the three sectors are presented in Table 3.

In general, the results of the estimated demand equations in terms of the predictive power of the equations, algebraic signs, numerical magnitudes, statistical significance, consistency, and plausibility of the estimated parameters were satisfactory. Log-log specification was only slightly better than the linear specification.

Turning to the residential demand first, the coefficients of all the explanatory variables had the expected signs, i.e., positive for income, number of connections, and temperature, and negative for marginal price and rainfall. All the coefficients, except for rainfall, were statistically significant at the one percent level. In the case of the commercial and industrial demand equations, all coefficients, except the rainfall coefficient in the commercial sector equation and the employment coefficient in the linear specification of the industrial sector equation, had the expected signs and, with only a few exceptions, were statistically significant. The positive sign on the rainfall coefficient (in the commercial sector demand equation) and the negative sign on the employment coefficient (in the linear specification of the industrial sector demand equation) were contrary to expectations, although the estimated coefficients for both variables were statistically insignificant.

The estimates of elasticities from both linear and log-log specifications of the estimated equations are presented in Table 4. In general, elasticity estimates from the linear specifications computed at the mean values of the respective dependent and independent variables for each of the equations were in line with those obtained from the log-log specification. For the residential sector, the price elasticity of demand was negative in sign, as expected, and statistically significant at the one percent level. However, it was found to be quite inelastic estimated at -0.18, implying that a 10 percent increase in the price of water will reduce the monthly water consumption only by 1.8 percent. This estimate compares favorably with previous studies conducted elsewhere, particularly those using time series. The income elasticity of residential water demand, estimated at 0.47, was positive and significant at the one percent level. This estimate indicates that a 10 percent increase in per capita income will increase the monthly water consumption by 4.7 percent. As with price elasticity, income elasticity of demand is also within the range of residential income elasticities estimated elsewhere. The weather variables are also found to influence the residential demand for water. The effect of the average monthly temperature is found to be significant and even much greater than that of rainfall. The estimate of temperature elasticity of 0.39,

Table 3. Estimates of Coefficients for Water Use in the Residential, Commercial and Industrial Sectors

Independent Variable	*Dependent Variable: Total Consumption*					
	Residential		*Commercial*		*Industrial*	
	Linear	*Log-Log*	*Linear*	*Log-Log*	*Linear*	*Log-Log*
Average price			-14943.73* (-1.05)	-0.17* (-1.09)	-17093.47** (-3.61)	-1.34** (-3.76)
Marginal price	-419453.58** (-3.35)	-0.18** (-3.53)				
Income	1765.28** (3.26)	0.47** (2.92)				
Connections	18.10** (11.65)	0.78** (11.45)	44.07** (8.87)	0.81** (8.99)		
Employment					-1.94 (-0.20)	0.39 (0.22)
Rainfall	-296.71* (-0.91)	-0.01* (-0.86)	44.70 (0.55)	0.72 (0.91)		
Temperature	103272.88** (3.07)	0.39** (3.16)	3003.21 (0.33)	0.34 (0.19)	2302.51* (1.38)	0.23* (1.26)
Adjusted R^2	0.95	0.95	0.83	0.83	0.59	0.59
DW –statistic	2.24	2.24	2.13	2.13	2.12	2.18

t-statistics are given in parentheses.
* Indicates significance at over 15 percent.
**Indicate significance at 1- percent level.

Table 4. Estimates of Elasticities by Sector

Variable	*Residential*		*Commercial*		*Industrial*	
	Log-log	*Linear*	*Log-log*	*Linear*	*Log-Log*	*Linear*
Average Price			-0.17	-0.17	-1.34	-1.15
Marginal Price	-0.18	-0.17				
Income	0.47	0.43				
Connections	0.78	0.79	0.81	0.80		
Employment					0.39	0.34
Rainfall	-0.01	-0.01				
Temperature	0.39	0.38	0.34	0.06	0.23	0.28

compared to rainfall elasticity of -0.01, indicates that, other things being equal, a 10 percent increase in the average monthly temperature will cause water consumption to increase by 3.9 percent. Finally, population as represented by the number of connections is also found to be an important determinant of residential water demand, with elasticity estimated at 0.78.

As with the residential demand, price elasticity of commercial demand was very low or inelastic, estimated at -0.17, which is almost identical to the price elasticity of the residential demand. This result should not be surprising given the fact that a significant part of the commercial sector in Sri Lanka constitutes an informal sector (home-based businesses, shops, etc.). Growth in this sector is also found to be an important determinant of the commercial water demand. Other things being equal, a 10 percent increase in the number of connections in the sector would increase water consumption by 8.1 percent. Rather surprisingly, weather variables are found to have no significant influence on the monthly water consumption in this sector, as indicated by the insignificant estimates of coefficients for both average monthly rainfall and temperature.

Unlike the residential and commercial sectors, price elasticity of the industrial demand was found to be high or elastic, estimated at -1.34, implying that a 10 percent increase in the industrial water price will decrease water consumption in this sector by 13.4 percent. The industrial water demand is, therefore, most responsive to price changes among all the water-consuming sectors. It should, however, be noted here that a large number of big industries, such as textiles, food, beverages and milk processing in Sri Lanka are located close to rivers. While most of these industries depend on the NWSDB's water supplies to meet their requirements, there is an increasing trend to use alternative sources of water such as groundwater and pumped river water. A survey of 34 and 68 industrial establishments conducted in 1999 in the north of the Kelani river and the North Colombo area, respectively, suggests that a large number of these establishments are increasingly using well water as an important source of their water supplies (Marikar, 1999). With an increase in real prices of water, the industrial sector is expected to continue to switch to alternative low-cost sources of water such as direct pumping from the ground and rivers, and this phenomenon is expected to continue until the ownership and allocation rights for these resources are clearly defined and regulated. Surprisingly, employment elasticity did not appear significant, perhaps reflecting that the number of employees was a poor proxy for industrial output or sales.

Conclusions

This study presents econometric analyses of demand functions, using monthly data from January 1994 to December 1998, and provides insights into the response of the urban water system by user category to exogenous changes. In general, the results of this study indicate that price can play an important role in urban water demand management. The price is found to have a significant effect on water demand, and this effect is much higher for the industrial sector than for the residential and commercial sectors. In addition, real income, number of connections (population) and weather variables are important determinants of urban water demand.

Our results support the view, and are consistent with studies conducted elsewhere, that industrial demand is highly responsive to price changes compared to the residential and commercial demands. A 10 percent increase in the price of water will reduce water demand in the industrial sector by over 13 percent. The high response in this sector basically reflects the fact that industrial establishments, being more motivated by economic factors than the residential sector, are more aware of both price changes and growing water scarcity. While price elasticity of the residential demand has been shown to be inelastic, price changes will certainly affect water demand. In quantitative terms, a 10 percent increase in the price of water would reduce water demand by 1.8 percent.

These results suggest that if a decrease in the amount of planned water consumption is desired, especially in an environment of increasing incomes and expanding overall economic activities, a mixture of instruments may be necessary. Simply raising the price of water may reduce industrial demand for water. However, substantial price changes would be required to overcome the positive effects of increasing incomes, to bring about desired changes in the residential and commercial water demands. The required price changes may be too substantial from a political point of view, so that other measures such as consumer education and awareness and investment in infrastructure to prevent water leakage/wastage may be necessary. It should be noted that any price increase in the residential sector should be such that the price increase is greater for high volume consumers than for small consumers using water for basic needs.

The results of this study are of direct relevance to water resource planning and policy making. The estimates of elasticities can be used in cost-benefit analyses of future water supply investment projects. Estimated values of economic variables from this study could be useful in future projects of sectoral water demand. Furthermore, given different socioeconomic and climatic conditions across regions in Sri Lanka, it would be useful to extend the present study to more disaggregated regional-level analyses. Cross-sectional analyses using variables such as household income, number and age of household members, size of house and area of gardens, household fixtures, water supply restrictions, and alternate sources of water would provide much greater insights into the factors influencing urban water demand.

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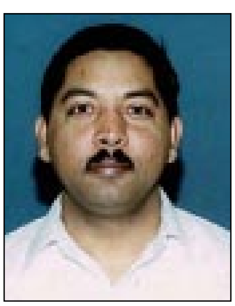

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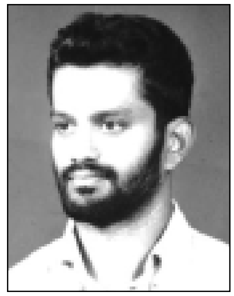

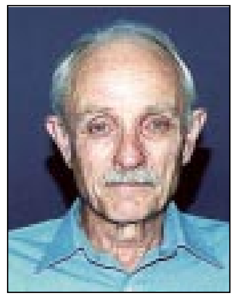

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