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A Coherent Approach of Statistical Modelling to address the behavioural status of water consumption and available water resources for semi-urban areas in Southeast Asia

Modele statystyczne zużycia wody dla różnych grup odbiorców z uwzględnieniem dostępnych zasobów wodnych na obszarach podmiejskich Azji Południowo-Wschodniej

Kiran Tota-Maharaj*) and Seevali Surendran*)

Keywords: *water resources, semi-urban, water consumption, forecasting models, sustainable water distribution, future planning, critical infrastructure*

Abstract

This study analysed recent water resources and water consumption datasets from semi-urban towns in the South Asian country of Sri Lanka. It presents a comprehensive assessment of behavioural status of water consumption over the past 5 years taking into consideration the impact on rainfall, precipitation patterns and temperature fluctuations. The findings provide important information on residential demand management and the threshold of consumption by residential users to apply in decision making process. Furthermore, this information informs policymakers, the water authority, and consumers not only in Sri Lanka, but across Southeast Asia and globally on critical water infrastructure, sustainable water resources and the applications of water forecasting for similar developing countries. The present observations contribute to the usefulness of statistical modelling methods in analysing, interpreting and understanding large datasets around available water resources and water consumption, providing reliable information to water utilities in reducing a tedious approach of water monitoring and assessment programmes in the region.

1.0 Introduction

Evaluating water consumption patterns could assist to gain insights on water consumption behaviour or to forecast water demand as an input for decision making processes in water distribution system operation policies and infrastructure planning. Water consumption can be divided into domestic, commercial, institutional, industrial, and agricultural use. The quantity of water delivered and used for each category is an important characteristic of water distribution, which influences future planning needs and assists in securing funds for water companies. The pattern of water demand fluctuates depending on various factors such as the purpose of use, time of day, standard of living, availability of sources and change of climate etc. There are very few studies on residential water demand in Sri Lanka (Gunathilake et al 2001; Hussain et al., 2002, Nauges and Van-den Berg. 2006) and only one study addressing industrial and commercial water demand (Hussain et al., 2002). Further to this, assessing water consumption using the real water consumption data are limited and providing a information based on the real data will provide a confidence to the planners and the designers.

1.1 Water consumption assessment

Techniques and methodologies for water demand assessment are widely available in the literature for developed countries; nevertheless, information based on reliable data is often unavailable for designers and planners to decide on future demand patterns. Methods to estimate future driving forces affecting the water distribution systems are fundamental, if robust and resilient management is desired. Future water demand is the main driving force in water system management (Gleick et al., 2003). This study focuses on a small area from a semi urban town in Sri Lanka, with the hope of providing a reliable information to address future demand.

1.2 Background information on the study area

Corresponding to current United Nations (UN) data, the population of Sri Lanka was estimated at 21.3 million and the population is growing steadily (**Figure 1**), even though the population growth rate is falling (**Figure 2**).

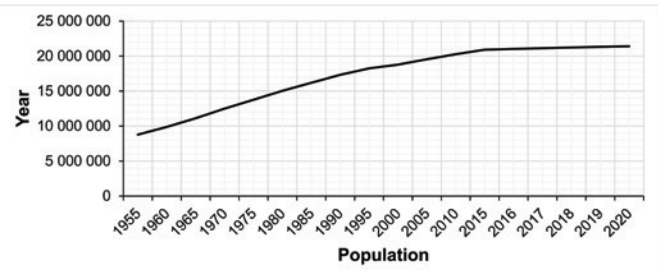

Figure 1: Population of Sri Lanka from 1960-2020. Adapted from: (Sri Lanka Population (2020) – Worldometer, 2020

Rys. 1. Ludność Sri Lanki w latach 1960-2020, źródło: Sri Lanka Population (2020) – Worldometer, 2020

*) **Kiran Tota-Maharaj** – Department of Civil Engineering, Aston Infrastructure & Sustainable Engineering School, College of Engineering and Physical Sciences, Aston University Birmingham, Birmingham B4 7ET, UK. Email: k.tota-maharaj@aston.ac.uk, **Seevali Surendran** – Environment Agency, Kings Meadow house, Kings Meadow Road, Reading, RG1 8DQ, UK. Email: seevali.surendran@environment-agency.gov.uk

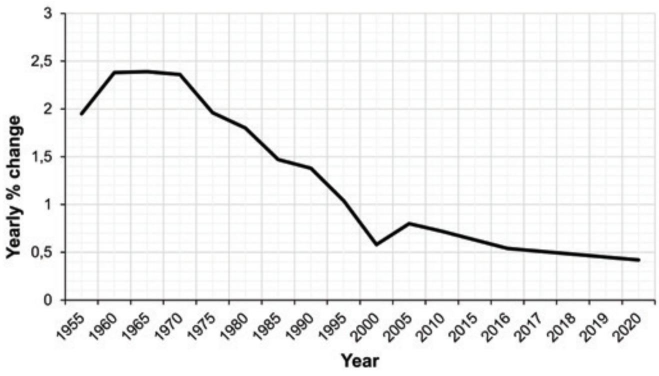

Figure 2: Yearly population growth rate (%) for Sri Lanka. Adapted from: (Sri Lanka Population (2020) – Worldometer, 2020)

Rys. 2. Roczna stopa wzrostu populacji (%) dla Sri Lanki, źródło: Sri Lanka Population (2020) – Worldometer, 2020

Zainudeen (2001) stated when planning water supply schemes, it is not advisable to consider standard growth rates, consumption patterns etc., because these depend on the type of population that is being catered to. It is important to recognise that the usage patterns would vary depending on cultural usage, livelihood, and size of land and weather patterns. Sri Lanka is a tropical country with clear dry and wet seasons and two monsoon seasons annually. There are two distinct rainfall zones in the country: the "wet zone," comprising the central mountains, and the southwest, which receives an average of 2,500 mm per annum. The "dry zone," comprising most of the southeast, east, and northern parts of the country, which receives significantly less annual rainfall ranging from 1,200 to 1,900 mm of rainfall annually. Average annual temperatures range from 28°C to 32°C.

1.2.1 Climate change impact to the water supply

There is a global issue with climate change and maintaining an adequate and uninterrupted supply of freshwater is a significant challenge to all countries. Further, climate change projections present an additional challenge to water demand modelling because of uncertainty regarding the magnitude of timing and even the direction of the changes that will be experienced in a specific location. Analysis of climate data for Sri Lanka clearly indicates widespread changes in rainfall and temperature (Statistics.gov.lk, 2019). It is expected, climate change will lead to altering the pattern and quantity of rainfall, evapotranspiration rates, surface runoff, soil moisture storage and availability of water sources for water supply and it will affect the consumption pattern of water.

1.3 Water distribution systems in Sri Lanka

The Sri Lankan Government targets to provide safe drinking water supply for all by 2025 with 60% of pipe-borne water supply coverage by 2020. The report from the Sri Lankan Department of Census and Statistics stated that 40% of the Sri Lankan population has established water supply facilities and approximately 60% are depending on other irregular sources such as wells, tube wells, streams and rivers etc., including 10% on unprotected sources. Several constraints have been identified in expanding the coverage of the water supply such as insufficient funding of capital and inadequate water resources. The National Water Supply and Drainage Board (NWSDB) in Sri Lanka is the national organisation responsible for providing safe and adequate drinking water supply, sewerage facilities and facilitating the provision of sanitation to all communities. It provides water supply and sewerage facilities primarily for residential, industrial and commercial establishments in urban areas and has recently extended the services to rural areas. The annual consumption of pipe-borne water through individual services covering residential, commercial, industrial and intuitional use has increased from 275 to 383 million cubic meters during the last decade (NWSDB, 2017). The NWSDB had an estimated 840,000 total water connections in 2004 and this figure had doubled by the end of 2013 (Mingyuan, 2015). Another feature characterising the evolution of Sri Lanka's water supply sector is the increased use in centrally managed water supply systems. In the 1980s, there were very few urban pipe-borne water-supply networks, most of the rural population was served by small gravity systems and dug wells. During the middle 1980s, a series of international programs got underway for scaling up district-level rural water supply systems that were to be operated by community-based organization schemes. These schemes delivered a further 500,000 water supply connections. This study selected a semi-urban town with an area of 250 km^2.

2.0 Case Study – Sri Lanka

2.1 Background

The datasets were collected from a semi-urban town in Sri Lanka which is located about 80 km east of the Capital Colombo and located on the wet zone of the country. The population for the study area is 67,962. The selected town for this study is named "Town A" for this study. The water treatment plant was constructed by the NWSDB with financial assistance from the Asian Development Bank.. The water treatment plant provides safe water to about 50,000 consumers in Town A (Table 1) and owned and operated by the NWSDB, Sri Lanka. All households and non-households are metered, and the data was collected from 01.01.2013 to 31.12.2017 through meter readings, which were taken monthly. The data set is based solely on historical records of water consumption.

Table 1. Overall information on the water distribution system

Tabela 1. Ogólne informacje o systemie dystrybucji wody

Constructed year	2007
Water Source	Giraduru Oya River
Number of Connections	11050
Peak Operating Flow m3 /h	345
Design Capacity of the town	540
Peak/Design flow	0.65
Number of operatives working at water treatment plant	1

Source: Cowi Consultants 2004, NWSDB 2014.

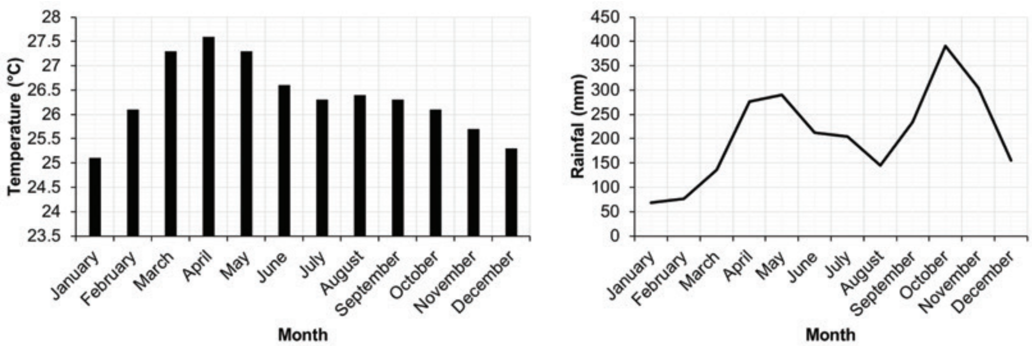

Figure 3: Town A (Sri Lanka) weather patterns by months graph. Adapted from: Climate-Data.org (2020)

Rys. 3. Roczne wzorce zmienności temperatury i opadu deszczu w mieście A (Sri Lanka), źródło: Climate-Data.org (2020)

2.2 Climate

The rainfall in the town was substantial, with precipitation occuring even during the driest month. The average monthly weather pattern is shown in **Figure 3**.

2.3 Methodology

To analyse Town A's water consumption patterns, monthly water consumption data were obtained from the NWSDB to use in this research. Data were collected using water meters installed on the premises. The water supply scheme of Town A delivers water to approximately 50,000 households and businesses in Sri Lanka. The demand area was divided into 3 areas namely Area 1, Area 2 and Area 3 for billing purposes. The data for these three areas were received for 5 years from January 2013 to December 2017 and data were separated and categorised on a yearly and monthly basis. To discover and evaluate water consumption, a series of applications were examined and applied. Firstly, the datasets were screened and sorted by months. This provided a quick reference to check the accuracy of datasets. If the points were homogeneously distributed and there were no negative points, this meant that the data was almost accurate. The monthly average water quantity for household, was calculated by dividing the monthly total water quantity of the user category by the total number of connections for each area. It was assumed that the average number for each household is four and to get the litre per capita per day consumption; the household quantity was divided by four. The data were transferred to the Minitab 18 statistical package and the data was fitted to probability models to find best fit.

3.Results and Discussion

In this study, the main focus was given to the domestic water consumption. The graphs were drawn to see the precedent on consumption from the year 2013 to 2017 for three different areas in the same town. The results are shown in (**Figure 4-Figure 15**). From the Figures it can be seen that, there is a increase of water consumption from year 2016. This is due to the second phase of construction; increasing the supply of water and new additional supply connections were completed in 2015 and new connections were fully operational from 2016.

Table 2. Water Consumption in Ml/month for months of January and February (2013-2017)

Tabela 2. Zużycie wody w Ml/miesiąc w miesiącach styczeń i luty (2013-2017)

January	2013	2014	2015	2016	2017
Area 1	59,311	55,325	67,743	120,919	92,796
Area 2	19,449	18,945	24,978	133,349	112,778
Area 3	33,292	42,852	42,918	77,264	56,466
February	**2013**	**2014**	**2015**	**2016**	**2017**
Area 1	60,753	71,187	67,456	111,419	72,673
Area 2	19,299	27,410	29,693	122,545	108,190
Area 3	36,028	47,615	42,220	71,030	55,545

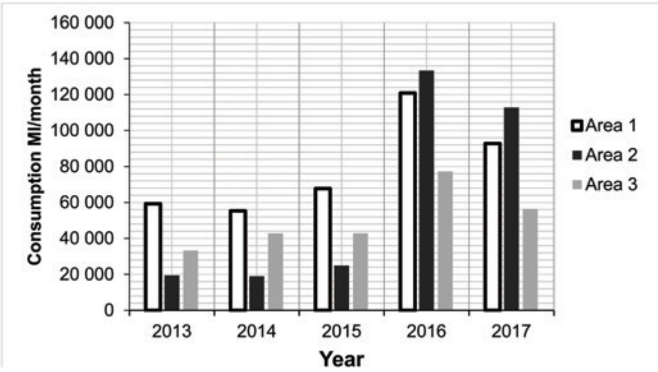

Figure 4. Domestic water consumption for three (3) areas in January in Sri Lanka, South Asia (2013-2017)

Rys. 4. Zużycie wody w gospodarstwach domowych dla trzech (3) obszarów w styczniu na Sri Lance, Azja Południowa (2013-2017)

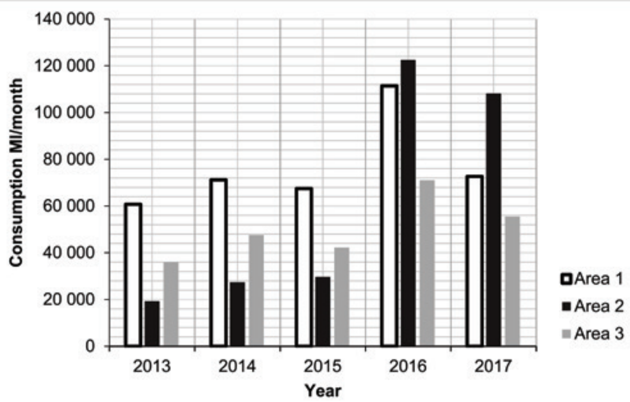

Figure 5. Domestic water consumption for three (3) areas in February in Sri Lanka, South Asia (2013-2017)

Rys. 5. Zużycie wody w gospodarstwach domowych dla trzech (3) obszarów w lutym na Sri Lance, Azja Południowa (2013-2017)

Table 3. Water Consumption in Ml/month for months of March and April (2013-2017)

Tabela 3. Zużycie wody w Ml/miesiąc w miesiącach marzec i kwiecień (2013-2017)

March	2013	2014	2015	2016	2017
Area 1	63,486	62,784	68,115	96,662	89,785
Area 2	22,068	28,088	28,079	118,308	99,772
Area 3	39,257	41,255	44,703	64,465	58,529
April	**2013**	**2014**	**2015**	**2016**	**2017**
Area 1	68,961	75,596	77,883	107,192	112,974
Area 2	25,104	27,086	32,068	129,108	129,040
Area 3	44,570	51,169	45,118	50,925	71,396

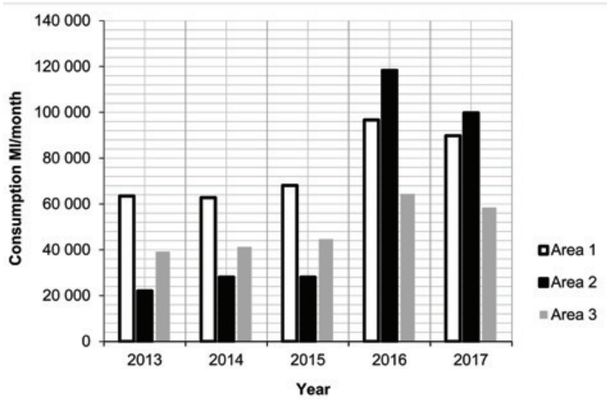

Figure 6. Domestic water consumption for 3 areas in March (2013-2017)

Rys. 6. Zużycie wody w gospodarstwach domowych dla trzech (3) obszarów w marcu (2013-2017)

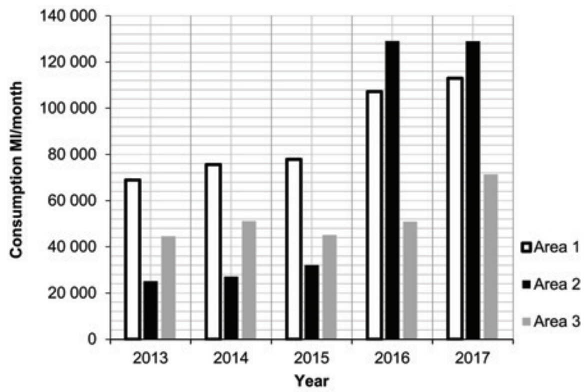

Figure 7. Domestic water consumption for 3 areas in April (2013-2017)

Rys. 7. Zużycie wody w gospodarstwach domowych dla trzech (3) obszarów w kwietniu (2013-2017)

Table 4. Water Consumption in Ml/month for months of May and June (2013-2017)

Tabela 4. Zużycie wody w Ml/miesiąc w miesiącach maj i czerwiec (2013-2017)

May	2013	2014	2015	2016	2017
Area 1	66,142	69,177	63,556	74,019	109,266
Area 2	25,535	33,999	31,064	37,655	130,703
Area 3	39,562	39,496	39,780	45,267	67,314
June	**2013**	**2014**	**2015**	**2016**	**2017**
Area 1	59,620	63,124	68,547	93,364	100,749
Area 2	23,696	27,838	28,680	104,549	123,755
Area 3	33,832	39,728	42,676	65,536	55,452

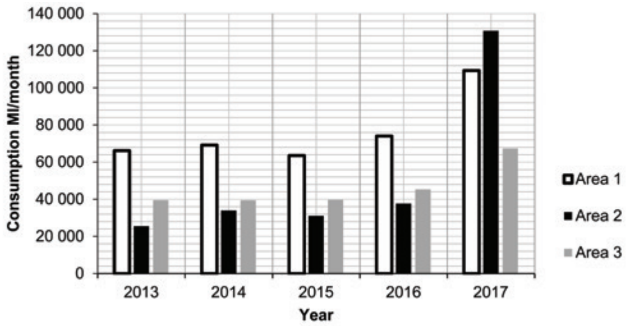

Figure 8. Domestic water consumption for three (3) areas in May (2013-2017)

Rys. 8. Zużycie wody w gospodarstwach domowych dla trzech (3) obszarów w maju (2013-2017)

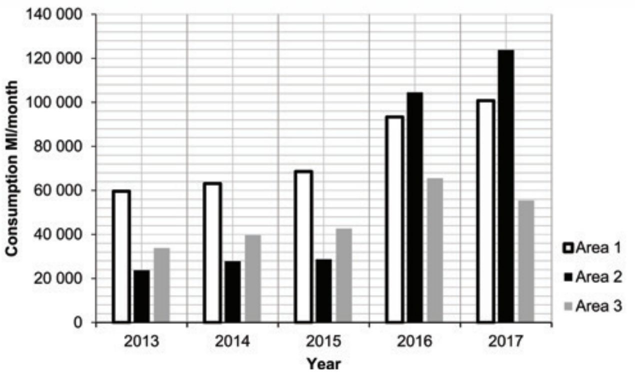

Figure 9. Domestic water consumption for three (3) areas in June (2013-2017)

Rys. 9. Zużycie wody w gospodarstwach domowych dla trzech (3) obszarów czerwcu (2013-2017)

Table 5. Water Consumption in Ml/month for months of July and August (2013-2017)

Tabela 5. Zużycie wody w Ml/miesiąc w miesiącach lipiec i sierpień (2013-2017)

July	2013	2014	2015	2016	2017
Area 1	58,559	59,665	77,902	105,755	92,363
Area 2	21,215	26,851	88,474	118,444	104,149
Area 3	34,904	38,707	54,952	63,618	58,475
August	**2013**	**2014**	**2015**	**2016**	**2017**
Area 1	78,185	63,851	95,952	69,653	97,875
Area 2	19,984	26,310	105,098	33,283	118,557
Area 3	44,667	39,156	66,721	48,305	59,989

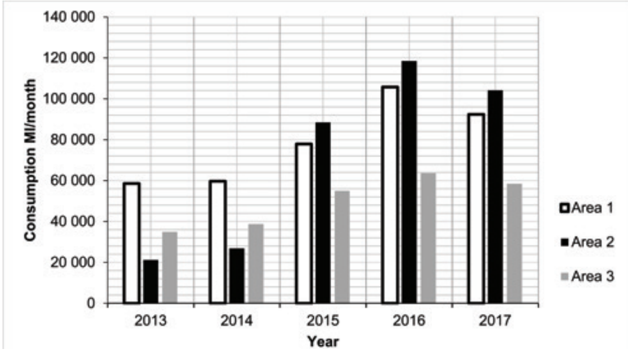

Figure 10. Domestic water consumption for three (3) areas in July (2013-2017)

Rys. 10. Zużycie wody w gospodarstwach domowych dla trzech (3) obszarów w lipcu (2013-2017)

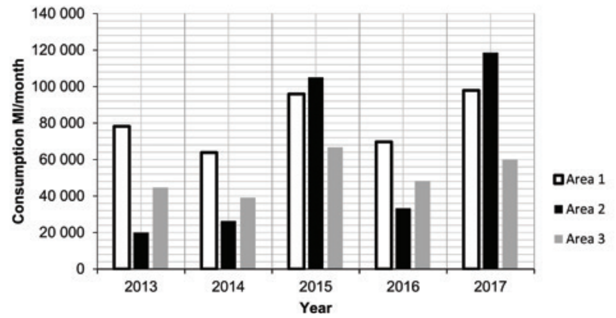

Figure 11. Domestic water consumption for three (3) areas in August (2013-2017)

Rys. 11. Zużycie wody w gospodarstwach domowych dla trzech (3) obszarów w sierpniu (2013-2017)

Table 6. Water Consumption in Ml/month for months of October and November (2013-2017)

Tabela 6. Zużycie wody w Ml/miesiąc w miesiącach wrzesień i październik (2013-2017)

September	2013	2014	2015	2016	2017
Area 1	63,393	67,524	97,594	87,135	101,474
Area 2	24,316	25,873	116,745	108,577	118,547
Area 3	36,839	41,957	66,464	53,034	55,252
October	**2013**	**2014**	**2015**	**2016**	**2017**
Area 1	58,069	67,301	99,582	91,796	87,833
Area 2	23,477	28,441	119,877	104,612	105,926
Area 3	36,492	37,827	61,347	53,043	49,838

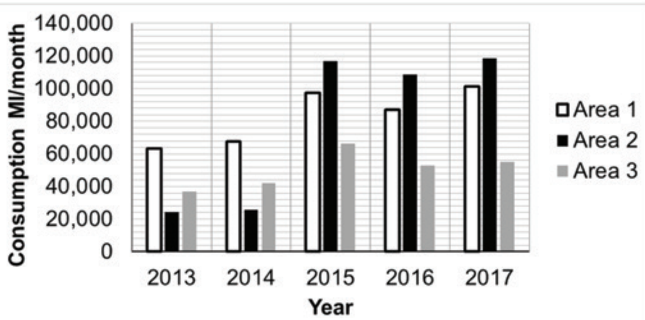

Figure 12. Domestic water consumption for three (3) areas in September (2013-2017)

Rys. 12. Zużycie wody w gospodarstwach domowych dla trzech (3) obszarów we wrześniu (2013-2017)

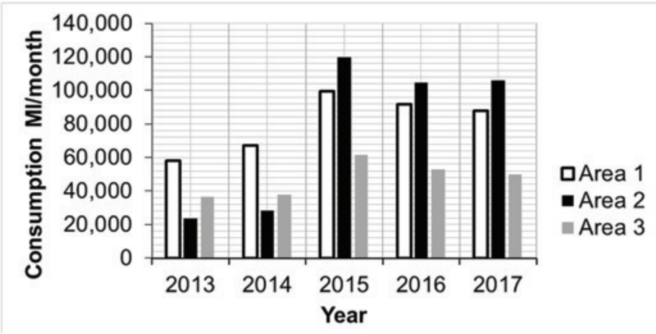

Figure 13: Domestic water consumption for three (3) areas in October (2013-2017)

Rys. 13. Zużycie wody w gospodarstwach domowych dla trzech (3) obszarów w październiku (2013-2017)

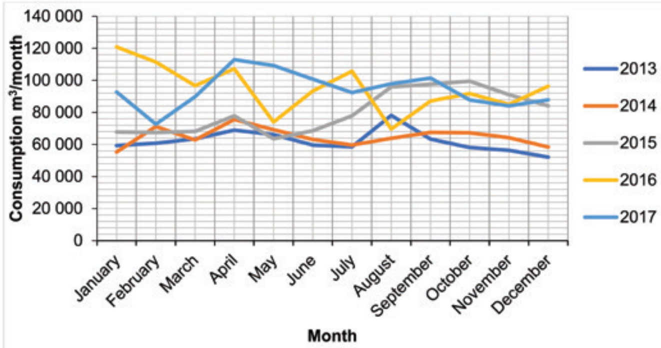

Figure 16: Mean Monthly Variation of water consumption from 2013-2017

Rys. 16. Średnia miesięczna zmienność zużycia wody w latach 2013-2017

Table 7. Water Consumption in Ml/month for months of November and December (2013-2017)

Tabela 7. Zużycie wody w Ml/miesiąc w miesiącach listopad i grudzień (2013-2017)

November	2013	2014	2015	2016	2017
Area 1	56,386	64,225	91,073	85,022	84,062
Area 2	22,746	26,223	111,812	98,966	96,216
Area 3	33,494	38,637	56,079	54,641	57,044
December	**2013**	**2014**	**2015**	**2016**	**2017**
Area 1	52,138	58,375	84,075	96,355	87,869
Area 2	19,961	23,751	103,988	111,461	112,348
Area 3	31,072	35,045	59,233	61,695	49,210

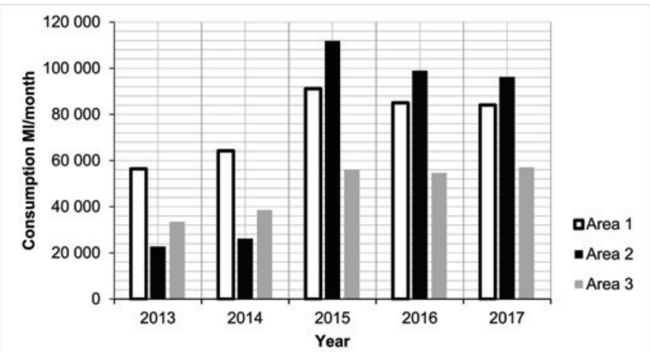

Figure 14. Domestic water consumption for three (3) areas in November (2013-2017)

Rys. 14. Zużycie wody w gospodarstwach domowych dla trzech (3) obszarów w listopadzie (2013-2017)

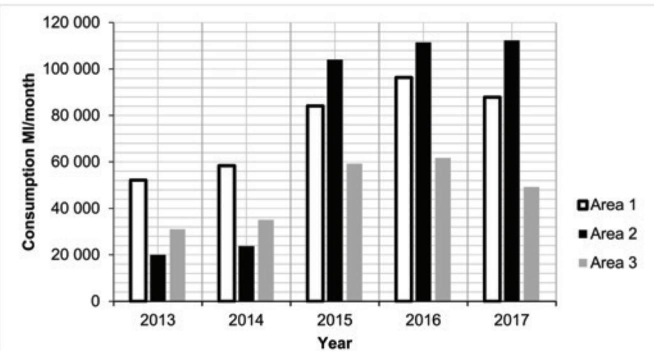

Figure 15: Domestic water consumption for three (3) areas in December (2013-2017)

Rys. 15. Zużycie wody w gospodarstwach domowych dla trzech (3) obszarów w grudniu (2013-2017)

Time-series graphs are best, to see the order of the pattern. Monthly variation in Area 1 was shown in Figure 16. There is a steady usage in 2013 and 2014. The capacity of the source increased in August 2015 and monthly consumption almost levelled off towards the end of the year. In the year 2016, low consumption is prominent in May and August.

The description of the categories is given in Table 8. The Percentage of household consumption for Town A was analysed and is shown in Figure 17. It shows that 70.58% of Town A's consumption is for households and the balance 29.42% is for nonhousehold purposes and wastage. In the UK 62% of the public water supply is used for domestic consumption, 30.1% is consumed by non-domestic purposes and 7.7% is lost in underground supply pipe leakage (EA 1999). One of the reasons for the high domestic consumption in Town A is due to a lower number of institutions and industries in the area owing to it being a semi urban town. Water consumption by different categories is important for future planning and each category for Town A is shown in Figure 18 – Figure 22.

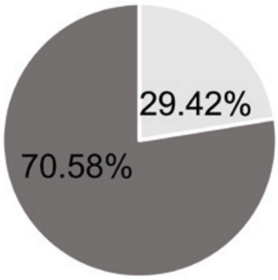

Figure 17. Average household consumption for the Town A in Sri Lanka, Southeast Asia as a percentage (%)

Rys. 17. Średnie procentowe zużycie wody w gospodarstwach domowych w mieście A na Sri Lance, Azja Południowo-Wschodnia

Table 8. Water use by different categories

Tabela 8. Zużycie wody dla różnych kategorii odbiorców wody

Category No:	Description	Category No:	Description
10	Domestic	70	Commercial Institutions
11	Board Quarters	71	Hotels and guest houses
12	Schools	72	Shipping
13	Gov. Quarters	73	Gov. Industrial Institutions
20-24	Subsidiary for low-income group	74	Export Processing Zones
60	Gov. Institutions	75	Small & Medium Enterprises
61	Police	80	Large Enterprises
62	Forces	90	Bulk Supply to Local authorities
63	Gov Hospitals	91	Bulk Supply to CBOs

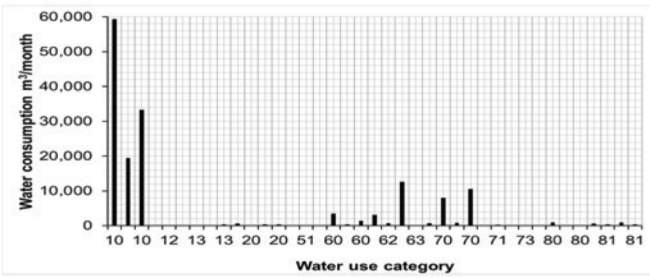

Figure 18. Water consumption for Town A for January 2013

Rys. 18. Zużycie wody w mieście A w styczniu 2013

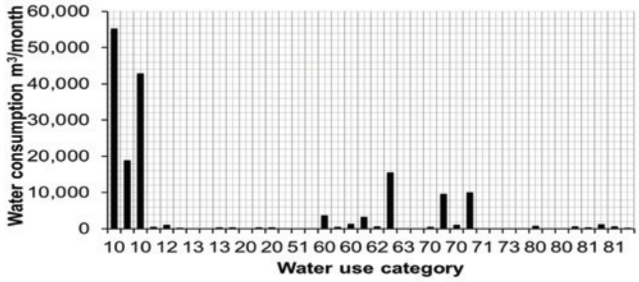

Figure 19. Water consumption for Town A for January 2014

Rys. 19. Zużycie wody w mieście A w styczniu 2014

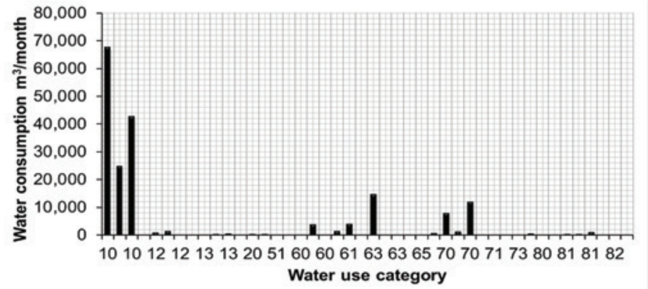

Figure 20. Water consumption for Town A for January 2015

Rys. 20. Zużycie wody w mieście A w styczniu 2015

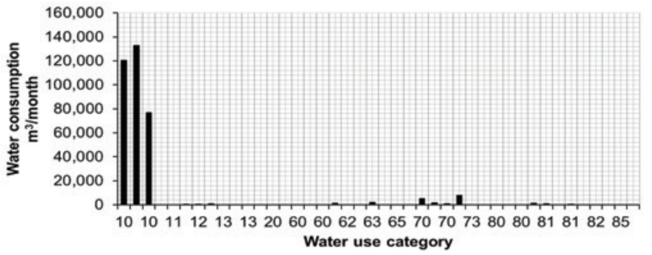

Figure 21. Water consumption for Town A for January 2016

Rys. 21. Zużycie wody w mieście A w styczniu 2016

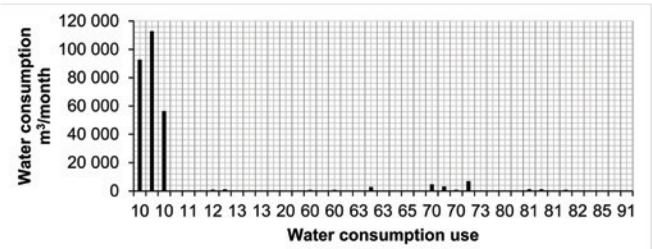

Figure 22. Water use by different categories for Town A for January 2017

Rys. 22. Zużycie wody w mieście A w styczniu 2017

Data from low-income families who get a subsidiary is illustrated in Figure 24; it is shown that the highest water consumption is 135 lpcd and the lowest is 60 lpcd for the Town A. It can be seen that there are no significant changes to the consumption patterns by having a reduced price for lower-income families in Sri Lanka and additionally this finding may be applicable to other developing countries.

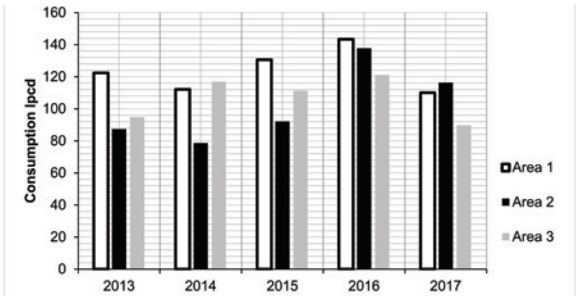

Figure 23. Average consumption per person for Town A (2013-2017)

Rys. 23. Średnie dobowe zużycie wody na jednego mieszkańca w mieście A (2013-2017

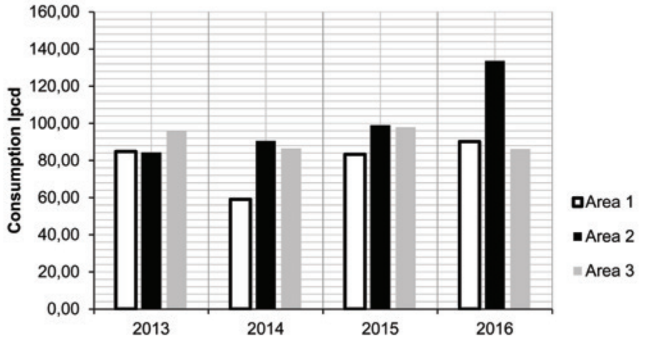

Figure 24: Average consumption per person for Town A with subsidy (2013-2016)

Rys. 24. Średnie dobowe zużycie wody na jednego mieszkańca w mieście A z dotacją (2013-2016)

To examine the effect of variation in temperature and rainfall (Table 9) in water consumption in Town A, graphs were drawn and shown in Figure 25. There is no significant correlation with temperature. This might be due to the fact that the temperature variation for the whole year in the Town A is about 2.5C0, meaning that the temperature change throughout the year is insignificant. The rainfall data was compared with the water consumption and it can be seen that where the rainfall is low in August there is a slight increase in water consumption.

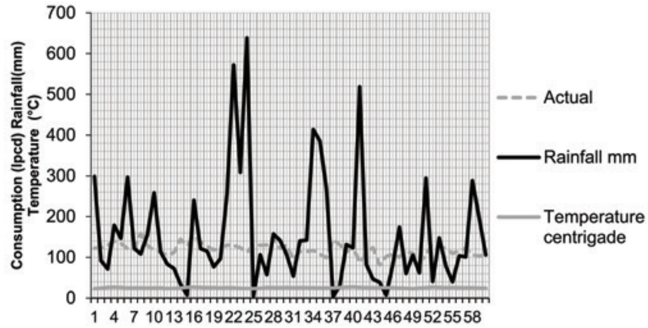

Figure 25. Town A water consumption – variation with temperature (C) and rainfall

Rysunek 25. Zmienność zużycia wody w mieście A w powiązaniu z temperaturą i opadami

Water consumption is quite high in this semi-urban town and it is almost similar to consumption in a developed country

3.1Fitting into Statistical Distribution Models

The above sections shown that the uncertainty is inherent in analyses of water demand because of the spatial and temporal distribution of measured data that contains random fluctuations based on variability due to environmental and social impact. It is crucial for engineering design that the distinction between variables with imperfectly known values be distinguished from variables characterized by randomly fluctuating values (Lund 1991). It is apparent from literature, still there is a gap in incorporating uncertainty of water demand applied in modelling. This study addresses this shortfall by finding a simple method to address the uncertainty in water consumption by fitting consumption data into a suitable probability distribution function. In this study it was observed that by analysing water demand data, the water demand has a normal or positively skewed distribution. The aim of this study is to investigate real water consumption data to determine a best fit statistical distribution to use in water demand modelling to address the probabilistic nature of water demand due to other factors. This study is expected to contribute to find a better fit water demand model for the Semi Urban town in a developing country. The work also has potential to provide a statistically proven method to forecast the water demand and help policy makers make decisions with confidence.

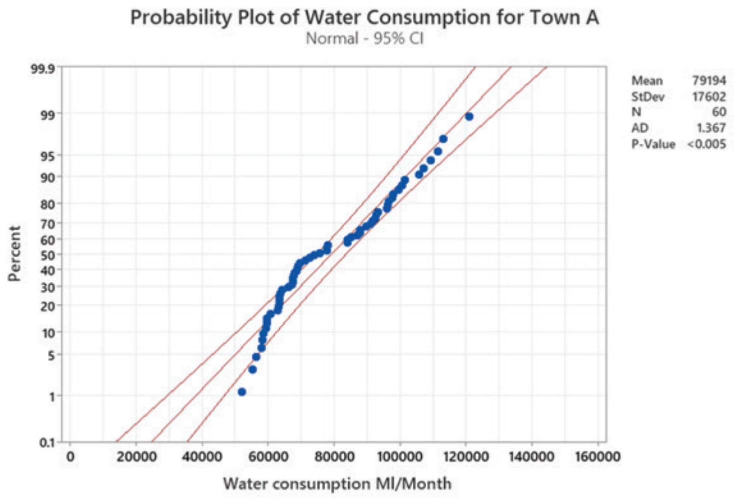

Figure 26. Normal Distribution fit for Town A

Rysunek 26. Jakość dopasowania rozkładu normalnego dla miasta A

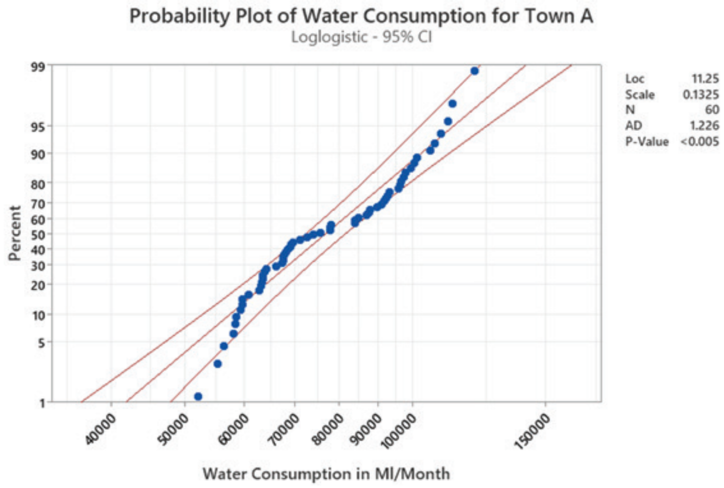

Figure 27. Log Logistic Distribution fit for Town A

Rys. 27. Jakość dopasowania rozkładu log-logistic dla miasta A

Data were analysed using the Minitab18 Statistical package and results are shown in Figure 26 and Figure. Figure shows the best fit model for the water consumption pattern for Town A is Log logistic Distribution with the low goodness of fit value compared to Normal distrbution.

4. Conclusion

This study used the recent water consumption data from a semi-urban town from Sri Lanka. It presents a comprehensive assessment of behavioural status over the past 5 years taking consideration the impacts of rainfall, temperature and subsidaries given to low-income families. The average consumption for Town A is shown in Figure 23 which illustrates that the highest water consumption is 140 lpcd and the lowest is 80 lpcd. The Sri Lankan per capita domestic consumption of water is between 140-160 litres per day, which is considerably high. Data from low-income families who get a subsidiary is illustrated in Figure 24; it is shown that the highest water consumption is 135 lpcd and the lowest is 60 lpcd for the Town A. It can be seen that there are no significant changes to the consumption patterns by having a reduced price for lower-income families in Sri Lanka and additionally this finding may be applicable to other developing countries. Comparisons were made to see if there is any correlation with rainfall and temperature and it can be concluded that it is not significant. The low consumption might be due to interrupted supply in the system. Further it shows that, this study also has potential to provide a statistically proven method to forecast the water demand and help policy makers make decisions with confidence. The best fit model for the water consumption pattern for Town A is Log logistic Distribution with the low goodness of fit value compared to Normal distrbution. The empirical evidence of this paper will provide important information on residential demand management. It will also provide the threshold of consumption by residential users to apply in decision-making processes. Furthermore, this information will inform policymakers, the water authority and consumers in Sri Lanka and will have applications for other developing countries too.

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