Winter 12-4-2017

Adopting IoT Technology to Optimize Intelligent Water Management

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Recommended Citation
Li, Eldon Y.; Wang, Wen-Hsin; and Hsu, Ying-Sung, "Adopting IoT Technology to Optimize Intelligent Water Management" (2017). *ICEB 2017 Proceedings*. 6.
http://aisel.aisnet.org/iceb2017/6

Li, E.Y., Wang, W.H. & Hsu, Y.S. (2017). Adopting IoT technology to optimize intelligent water management. In *Proceedings of The 17th International Conference on Electronic Business* (pp. 38-46). ICEB, Dubai, UAE, December 4-8.

Adopting IoT Technology to Optimize Intelligent Water Management

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ABSTRACT

Intelligent water management (IWM) has been used to study the supply and demand of tap water in Taiwan. This research aims to enhance existing and future water utility management. Leveraging the *supervisory control and data acquisition* (SCADA) technology that connects sensors to a distributive infrastructure, the system detects leaks, assesses quality, monitors discharge, and manages assets of water utility. In this paper, we propose a prototype of urban intelligent water system by installing an intelligent water meter. Three steps are undertaken to demonstrate the IWM: 1) choose the way of data transmission; 2) establish communication equipment and generate cloud database; and 3) apply big data analyses and value-added applications. By intelligently managing the water supply system, it generates benefits of saving water, saving energy and optimizing water resources dispatching.

Keywords: Smart city, IoT, intelligent water management, cloud database, big data analysis, technology adoption

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INTRODUCTION

With the coming of smart city, new life style will overturn traditional modes. It offers people diverse and convenient living environment by utilizing *Internet of Things* (IoT) techniques including combination of cloud storage, internet transmission and sensor devices. By adopting big data analysis, valuable data extraction and following applications, people are provided with more diversified and convenient quality environment (Tsai, Lai, & Vasilakos, 2014). The supply and demand of tap water in Taiwan have been studied with the purpose of enhancing not only current but also future water utility management (Jung et al., 2015). By installing of intelligent water meter, choosing the way of data transmission, establishing communication equipment and cloud database, and applying big data analyses and value-added applications, we propose a prototype of urban *intelligent water management* (IWM). The key factors to construct intelligent water network are joint planning of *district metering area* (DMA) and *automated meter reading* (AMR) while intelligent water meter plays an important role in both systems (Ying et al., 2016; Joo et al., 2014). It would be more promising to promote water saving action concurrently with incentive measures, such as lowering water charge by taking advantage from the specified applications. With this approach, the urban intelligent water system will be constructed step by step in the near future. This study is aimed to strengthen the public water supply particularly by adopting IoT technology, link front-end data acquisition and back-end cloud storage, to propose a practical application category for further water system and IWM projects. To prepare for the future in water environment perspective, we are on the way directing Taiwan towards a developing IWM country. By utilizing comprehensive analytics and alert systems, the way we monitor and manage water network will be much improved. With more data insights and control functions, *Taiwan Water Corporation* (TWC) is able to enhance operational efficiency and make strategic decisions better.

LITERATURE REVIEW

Smart city concept

A city is an interconnected system of systems with a dynamic work in progress and “progress” being its watchword. A smarter city is one that accelerates its journey towards sustainable prosperity by making use of new smart solutions and management practices (IBM, 2017). In a smart city we support the deployment and integration of ICTs (Information and Communication Technologies) including wireless and broadband connections, advanced analytics software and intelligent sensors to achieve significant improvements in life efficiency and quality; and to help change behavior among residents, businesses and government. Eventually, cities can grow in a more sustainable way (Badii et al., 2017). Many cities are exploring the smart-city concept to improve efficiencies, optimize how human beings use limited resources and let the earth become a better place to live. The targets of smart cities are interconnected with sustainability goals (Albino, Berardi, & Dangelico, 2015).

Water scarcity

According to the assessment of Ministry of Economic Affairs in Taiwan, the development of new water sources is rather difficult. When water scarcity becomes a big issue, we must establish normal mechanisms to deal with this fact. Due to that most high-tech industries were developed in central and southern Taiwan, the space-time distribution of rainfall is uneven (Sharma & Swamee, 2013; Suen & Herricks, 2015). In order to overcome flooding, leakage, usage and retention, Taiwan has developed its own water conservation industry. Its scope is water investigation and research, technical consultants, engineering construction, operation management, product manufacturing, information system, and etc. Nowadays, Taiwan government (2016) has been centralizing resources to promote insightful infrastructure projects. In water environment construction part, it is planned to build a smart flood control network, regional dynamic groundwater intelligent operation and management monitoring network, tap water intelligent water network, intelligent river tube system, intelligent operation management of multi-target reservoirs and sophisticated irrigation water saving and other intelligent water environment sensing system, as well as the construction of IWM system. It is multi-pronged and expected to make the domestic water resource utility and flood control more effective (Hung, 2004; Yang, 2005).

IoT development

The IoT is a novel paradigm shift in IT arena. IoT technologies can seamlessly integrate classical networks with networked instruments and devices. It has been playing an essential role ever since it appears which covers from traditional equipment to general household objects (Jing et al., 2014). The Internet is a global system of interconnected computer networks that use the standard Internet protocol suite (TCP/IP) to serve billions of users worldwide. It is a network of networks that consists of millions of private, public, academic, business, and government networks, of local to global scope, that are linked by a broad array of electronic, wireless and optical networking technologies. While it comes to things, they can be any objects or persons which can be distinguishable by the real world. Everyday objects include not only electronic devices we encounter and use daily but also technologically advanced products such as equipment and gadgets (Biddlecombe, 2009). It is a new ICT to strengthen services across different sectors and to build an intelligent digital neural system supporting urban operations. The IoT aims to unify everything in our world under a common infrastructure, giving us not only control of things around us, but also keeping us informed of the state of the things (Nunberg, 2012; Gubbi et al., 2013).

District Meter Areas

District Meter Area (DMA) is defined as an area of the supply network having ideally about 2000 properties supplied preferably from a signal entry point which is metered (e.g., water entering or leaving point) and pressure controlled (MacDonald & Yates, 2005). The main objective of establishing a DMA is to reduce real losses to an economically acceptable level and maintain this level through the application of proactive strategies, such as Active Leakage Control. The technique of leakage monitoring is the major contributor to cost-effective and efficient leakage management (Sturm & Thornton, 2005). The application of DMA concept has universal application in any network and this technique is reliable for leakage reduction and monitoring (Farley & Trow, 2003).

Intelligent water management

The International Water Association (IWA) water methodology is all about accountability and an integrated approach to water loss control. There is a standard water balance in a place for everything as shown in Table 2 (Lai, Weng, &Roy, 2017; Yates, 2005). There were numerous examples of the use of AI methods for the management of selected tasks within the water supply system. Artificial neural network model with genetic algorithm was used to create pressure management model for urban water distribution networks. A technique used for leakage reduction is pressure management, which takes the direct relationship between leakage and pressure into account (Giustolisi, Savic, & Kapelan, 2008; Nasif et al., 2010). The operational monitoring and control involve detection of pipe leakages.

Table 2. IWA Standard Water Balance

System Input Volume	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non Revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Apparent Losses	Unauthorized Consumption	
			Customer Meter Inaccuracies	
		Real Losses	Leakage on Transmission & Distribution Mains	
			Leakage and Overflow at Reservoirs	
			Leakage on Service Connections up to meter point	

RESEARCH METHODS

The sources of this study are based on the open data released by the website of TWC and SCADA system built in DMA of Datong small area in Taichung Wu-Feng district, Taiwan. The geographical location and DMA of this research was shown in Figure 1. The total number of water users is 481 households, the overall length of pipeline is 9.4 kilometers, and the majority of residents in this area are households and public facilities.

The overall intelligent water structure can be divided into four parts: front-end data acquisition, network transmission, cloud storage, and analysis applications. First, it is the sensor layer. The sensing equipment of the tap water is mainly used for the position of the front-end water inlet after planning DMA, as shown in Figure 2. The use of the sensor equipment includes water meters, water pressure gauge, etc. Regarding water meter, both mechanical and electrical water meter have been used through its own built-in microcomputer function. The C-class electromechanical integrated water meter contains a multi-function management system and record function capable of sensitive metering and managing water resource; it is known as the intelligent water meter (Yang, 2009; EMS, 2017). The low-discharge-sensing instrument actively detects water leakage and triggers alarm. It not only improves the metering but also reduces the water-leakage bill and non-revenue water charges. Moreover, it improves the water bill rate and meter accuracy rate. With the communication device and gateway, managers can remotely monitor water meter without sending people to get the raw data (Arregui et al., 2012).

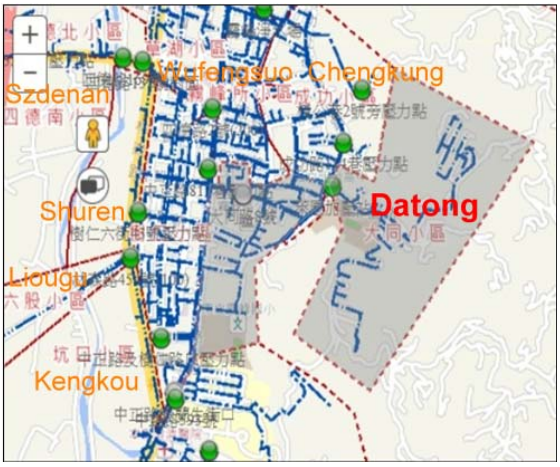

Figure 1. Datong small area of Taichung WuFeng district in Taiwan

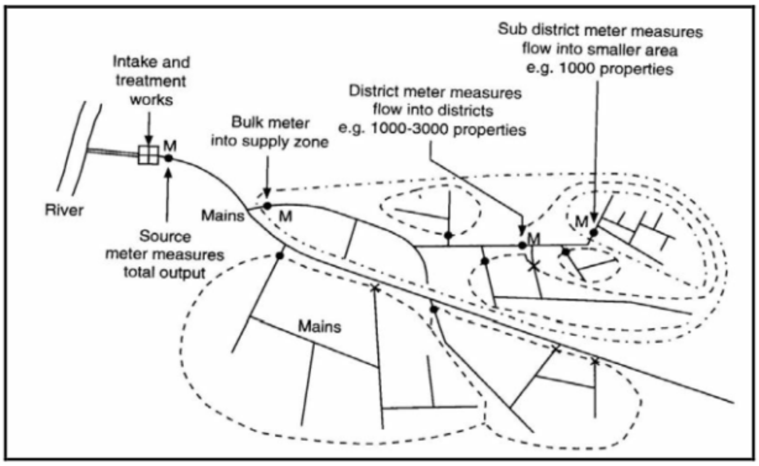

Figure 2. Public water supply system intelligent management of the advanced research program (WRA MOEA Taiwan, 2016)

Considering data type, transmission ways, and storage methods, we used AMR and applied IoT technology to build SCADA system in studied area for 6 months (Turc, Gligor, & Dumitru, 2017). In the area, a closed DMA was installed with an intelligent water meter, which can measure the flow range of 0.525 ~ 70 m^3/h. In addition to intelligent water meter, an electronic pressure gauge was installed at both the entrance point and a pressurization station. Then we collected the time series data including discharge rate and pressure level.

As for communication layer nowadays, the data transmission technology is quite diverse depends on signal interference, transmission distance, transmission time, battery power supply time, transmission frequency and technology, as shown in Table 1 (Song et al., 2017). The power-saving and long-distance transmission of LPWAN (*Low-Power Wide-Area Network*) is more advantageous (Xiong et al., 2015). Current use of data transmission mode in this studied area was mobile communication, as shown in Figure 3, mainly through 4G LTE wireless communication recorder to send the information to the base station, and then through the cable/wireless network or SMS to personal computers, servers, or personal mobile phones for analysis and application.

Table1. Automatic communication technology

	Technology	Apply to	Unfavorable to
LAN (Local Area Network)	Bluetooth ZigBee WiFi	Mobile terminal, Indoor Short-term communication	Bow battery life Long-term communication
LPWAN (Low Power Wide Area Network)	Sigfox LoRa RPMA	Long-term communication Long battery life Low cost	High data volume
Cellular	GSM 3G+ 4G LTE	Long-term communication High data volume	Battery life High cost

Regarding data storage, analysis, and application, it often uses cloud computing. The main reason is that users can use browser to access all software anytime and anywhere. The advantage of using cloud computing is reliability and high availability in storage center. The requirement of the hardware in the font-end side is relatively low threshold, and use of software to facilitate the sharing of information between different devices and application services. In conclusion, cloud is not only a place to store data from sensors but also provides data analysis and application.

The data analysis technology includes statistics, machine learning, data exploration, forecast analysis, and others. It reveals knowledge and insight from various types of structured and unstructured information. Compared with the traditional data mining technology, big data analysis features must include four kinds of computing technology: large amount of data storage and computing power, parallel computing algorithm, complex and sparse data analysis, dynamic, real-time and incremental operations. The common data analysis methods are mostly statistical, but the analysis of big data is still the key to the solution of the problem. To understand the type of information and the background of the data, we use analytical methods/techniques to get what we want.

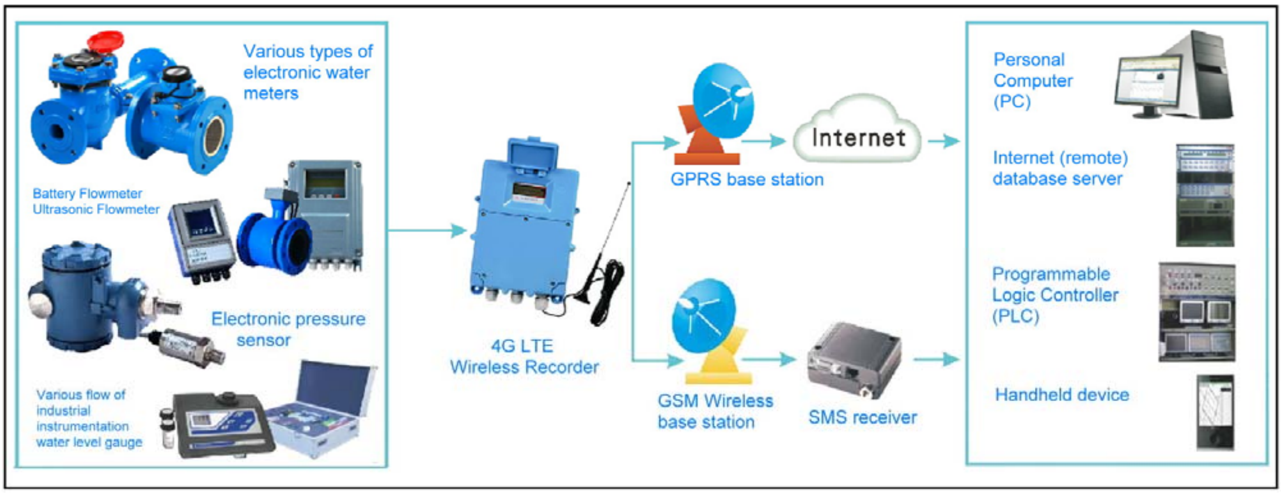

Figure 3. The way of intelligent water meter

RESULTS AND DISCUSSIONS

Time series data

Based on the analysis of the discharge and pressure sequence data of the Datong small area in Wu-Feng district, the two data recording formats are saved into CSV file format, and the discharge time statistics are from 9:21 am on January 12, 2017 to midnight on June 11, 2017. The observation period is about six months with data recording once per minute, a total of 215,511 data points. The raw data will be preprocessed by the Python programming language and the built-in kit will be used for data analysis. The discharge and pressure original time series are shown in Figure 4 and Figure 5.

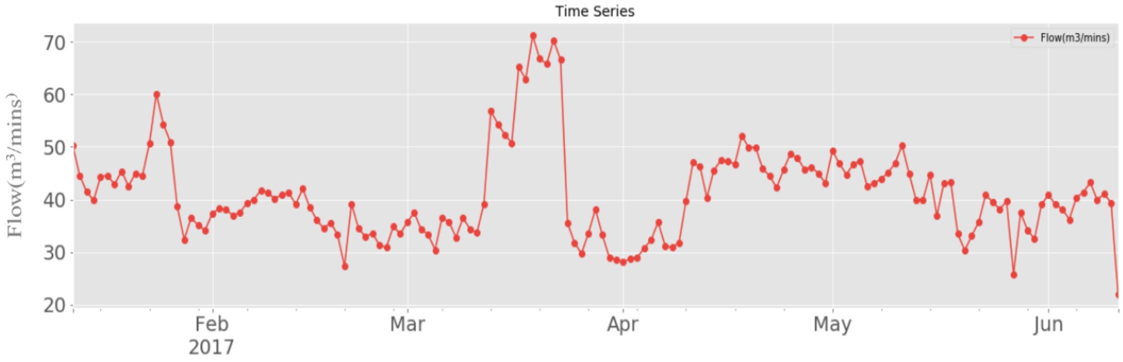

Figure 4. Discharge time series data

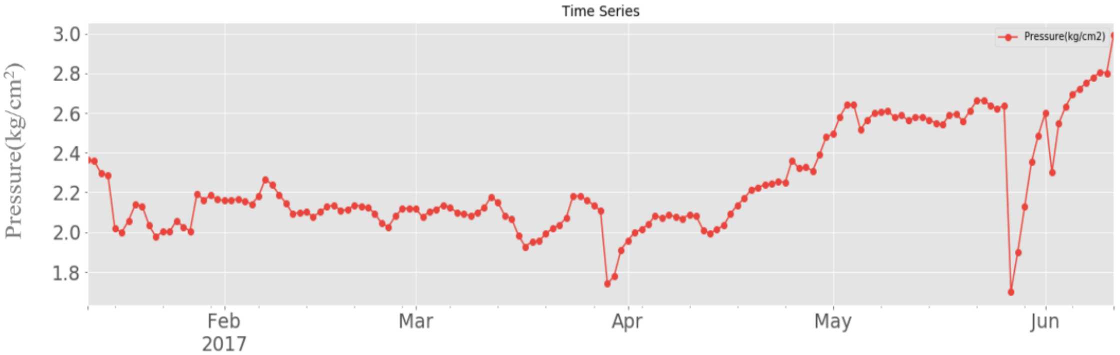

Figure 5. Pressure time series data

Probability density function (use water level query)

Water supply depends on the fact whether water pressure is sufficient, water yield is sufficient, leakage is minimized, and water quality is acceptable. The major four problems in this time series data analysis only focus on the discharge as the probability density function which has been expressed as the following formula:

(1)

$$f(X) = \lim_{\Delta x \to 0} \frac{P(x \le X \le x + \Delta x)}{\Delta x} = \lim_{\Delta x \to 0} \frac{F(x + \Delta x) - F(x)}{\Delta x}$$

Where X is arbitrary variable, P is probability, F is cumulative probability function, and f is probability density function of variable X. Herewith, X is the discharge, and the results are shown in Figure 6 and Figure 7. Horizontal axis is discharge or pressure, and the vertical axis is its density. To understand the proportion of each variable, the horizontal axis unit must be multiplied by the density value. It can be observed that the water peak of household was concentrated in 40 ~ 44 (m^3/hr), 0.11 ~ 0.12 cms with the share about 48%; and the pressure distribution was concentrated in the 2.0 ~ 2.2kg/cm^2 with the share about 28%. Besides, the statistical discharge and pressure of the kurtosis and skewness were shown in Table 3. The water pressure was relatively high in two of kurtosis as the peak value was relatively centralized. The variation of the pressure distribution was usually small, and the variation of the discharge was larger. The value of the skewness reflected the right deviation of the discharge, indicating that the discharge rate was higher than ordinary. While the pressure was left deviation, indicating that it was in lower water pressure most of the time. After checking, this user was a library. The probability density function can provide users with simple information to understand the water level is at which range, and the user can use this data to determine whether the water is sufficient.

Table 3. Variance kurtosis and skewness statistics

Item	Kurtosis	Skewness
Discharge	-0.31	-0.50 (flush right)
Pressure	-0.90	1.06 (flush left)

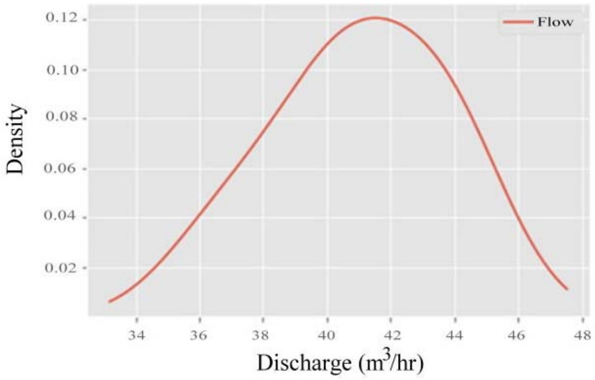

Figure 6. Discharge probability density function

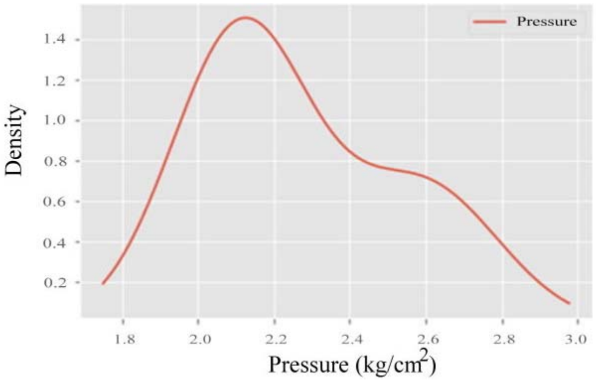

Figure 7. Pressure probability density

Abnormal value analysis (possible leak assessment)

If there is an abnormality in the discharge time series data, it may be that the user suddenly increases water consumption or does not use water for a long period of time. However, if there is an abnormal value, there should be a situation of a broken water pipe. Therefore, it can use the quartile method (outlier analysis) for the data analysis. In Figure 8 and Figure 9, the quartiles were Q1 for 20.4, Q2 for 33.6, Q3 for 61.2, the maximum/result for 122.4 122.4 from Q3+(Q3-Q1)*1.5, and the minimum/result for -40.8 from Q1-(Q3-Q1)*1.5. Because the water discharge was no negative value, the result we used zero instead of -40.8. Where Q1 represented the first 25%, Q2 represented 50%, Q3 represented 75%, more than the maximum upper limit of those who were abnormal. It showed the time of occurrence, compared to water conditions, can be further clarified that water consumption was increased or broken pipe caused.

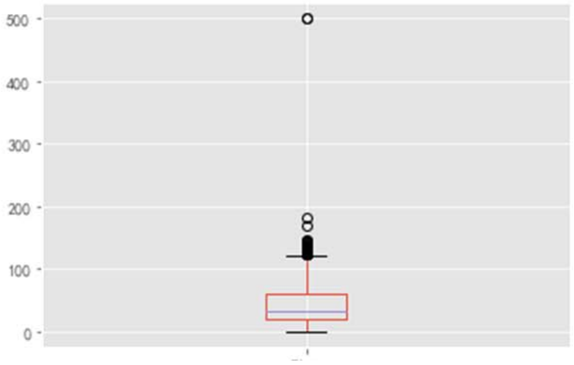

Figure 8. Discharge box chart (m^3/h)

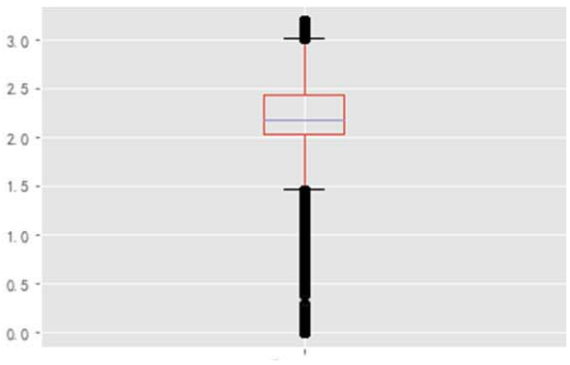

Figure 9. Pressure box chart (kg/cm^2)

By water pressure analysis, the quartiles were 2.04 for Q1, 2.17 for Q2, 2.43 for Q3, the maximum is Q3+ (Q3-Q1)*1.5 = 3.015, and the minimum is Q1- (Q3-Q1)*1.5 = 1.455. Figure 9 shows that the minimum pressure occurs many times. If broken pipes appear, the criteria can be judged by a sudden increasing water discharge and dropping water pressure. When the two scenarios occur close to the time, it can determine the user should have water leakage in this situation. If both data are outliers from intelligent water meter once per minute, the system can immediately notify the user that there may be water leakage occurring and recommend further actions to take as soon as possible.

Time series analysis (using water behavior statistics)

For user water behavior statistics, the cycle is often observed by time, day, week and month. The current data collection was only six months as shown in Figures 10 ~ 14, which show the water consumption was low in February, peak in January and decline in April, May and June. After checking, we found the district in question has many public facilities and it was the Chinese New Year holidays in February, not opening for a long time, so the discharge was lower relative to other months. Furthermore, we analyzed monthly single-day water statistics and found the discharge water was centralized in the middle of the month. The beginning and end of the month were the time that water is relatively less consumed. Among a day, the discharge is low during 2 to 6 am in the morning and 1 to 3 pm in the afternoon. It was at the peak at 4pm and then gradually decline to 9pm in the evening. The highest discharge was at 10pm and then quickly decline. From the observation of pressure distribution, the most sufficient pressure period was 4 to 5am in the morning and the next peak time was 1 to 3pm in the afternoon. In contrast, the discharge distribution was lowest during 1 to 3pm. It showed a significant inverse relationship between those two parameters. If users wanted to use plenty of water, it was recommended the above-mentioned two time blocks during the day according to the water pressure distribution. Therefore, users can choose the appropriate time to water plants or clean houses during 1 to 3 pm.

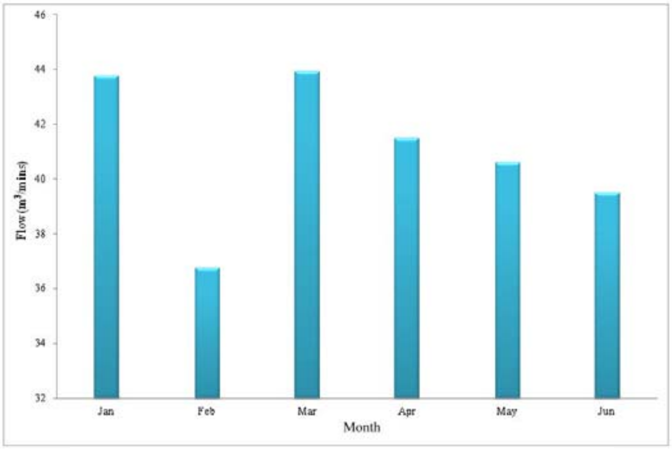

Figure 10. Monthly average water

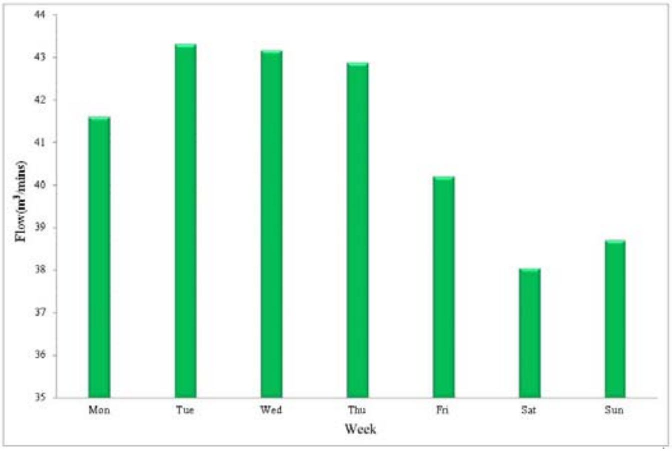

Figure 11. Weekly average water consumption

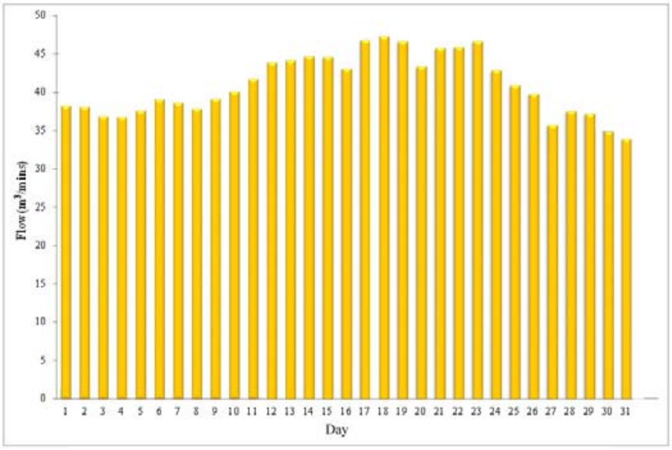

Figure 12. Daily average water consumption

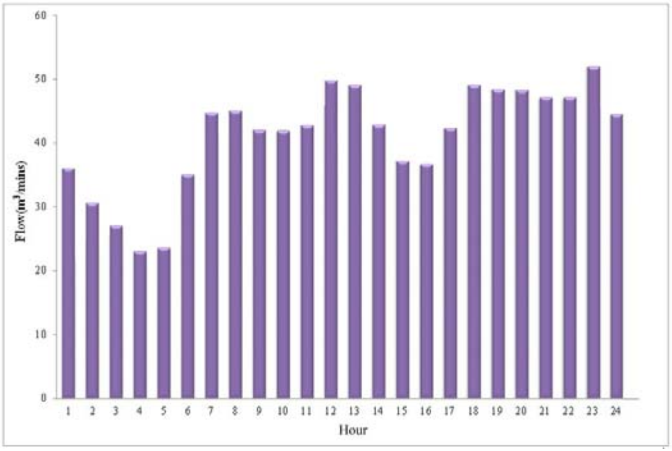

Figure 13. Hourly water pressure distribution

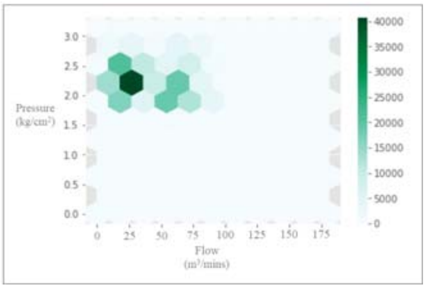

Figure 14. Discharge and pressure hexagonal bin plot

Primary and secondary factor an

According to the main factor analysis, we understood the peak time of user's water demand as shown in Figure 15 ~ 17. The results show 80.8% monthly water consumption was concentrated in the middle of the month and 86.8% of monthly water was consumed on Monday to Saturday; 82.2% concentrated in the morning and evening hours. These could provide a decision-making basis for water supply to the end user. For example, it was recommended the appropriate time of stopping water supply should be in the end of the month or the early of the month, the date should be in the weekend, the time in the morning from 1 to 5 am, because the user consume less water during this time and the impact is lowest. In addition, the user can also get real-time notice for storing water when there was scheduled to stop the water supply. Based on the user daily water consumption statistics, one can determine the date and period of stopping water supply and evaluate whether the water in storage tower is sufficient or not for the preparation in advance.

Water quality status inquiry

In this study, we used data mining techniques to analyze the water discharge, pressure, and quality data for several valuable applications. Furthermore, we provide an APP for public to evaluate water quality status including residual chlorine, turbidity, and PH value as shown in Figure 18: “House Leakage Notification in Five Minutes”, “Water Supply Inquiry and Water Cut Off Notification”, “Abnormal Water Quality Monitoring”, and “Intelligent Water Housekeeper”, which can be used to inquire the water quality of the water purification sites announced by TWC. More information can be provided in the future for further applications. In addition, the online web query function is also available for real-time checking.

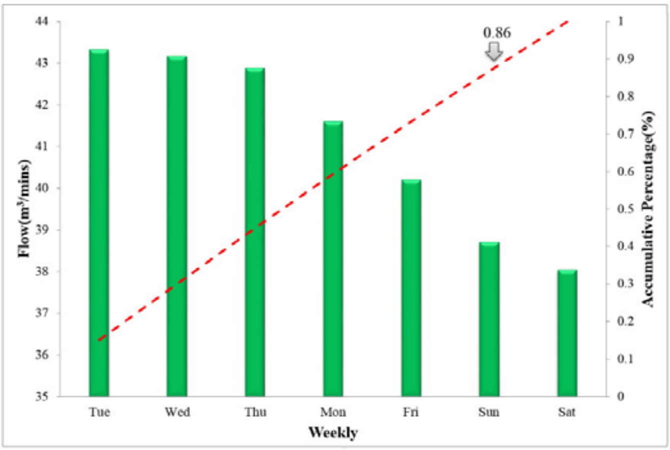

Figure 15. Weekly water analysis in one month

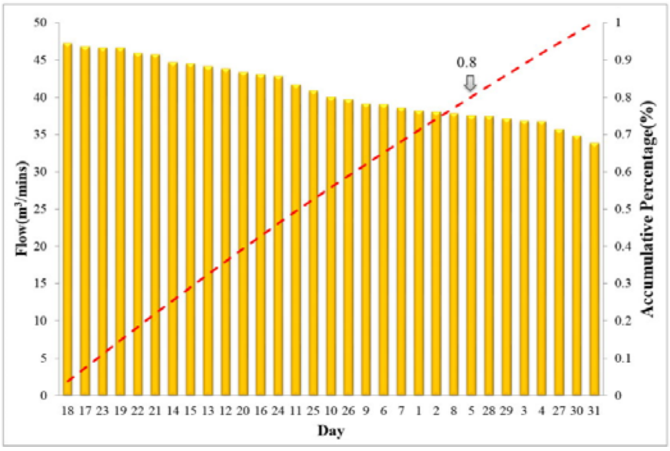

Figure 16. Daily water analysis in one day

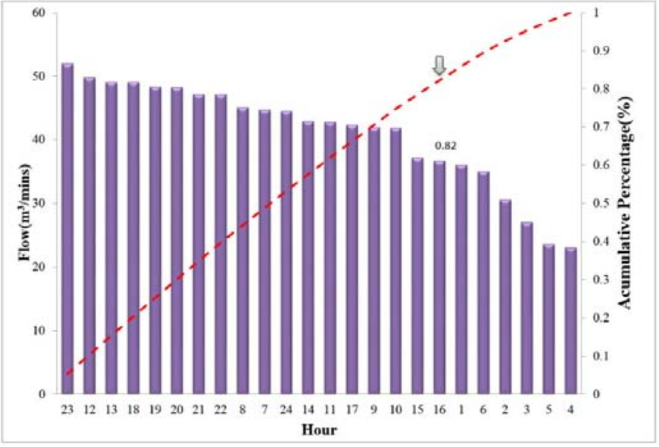

Figure 17. Hourly water analysis in one day

Figure 18. APP for water quality inquiry

CONCLUSIONS

The intelligent water metering is the key to IWM, but higher water charge is not the incentive to its development. The main problem is still about that the value of installing smart water meters is considered as non-cost-effective and unnecessary. Taiwan has advanced ICT and uneven water resources distribution; it could be one of the most suitable regions to adapt IoT technology to develop IWM in this water scarcity environment. Smart city is a growing issue, and key success factors are the analysis and application of big data. More investment on research and development from government and industries are essential to make relevant applications become more diverse and valuable in the near future. We also encourage government to release more information and data categories in an open platform and welcome diverse groups to discuss and provide their creative ideas for building intelligent water system in Taiwan.

ACKNOWLEDGMENT

The research is partially supported by Ministry of Science and Technology in Taiwan (Grant No.106-2410-H-004 -052) and the Water Resources Agency, MOEA, Taiwan, R.O.C.

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