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Formulizing the Design Criteria for Piped Water System in Cambodia: A Case Study in Anlong Romiet Water Supply

Davin Sang[1,2*], Meng Chhun[1], Sambo Lun[1,2]

[1] *Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia, Russian Federation Blvd., P.O. Box 86, Phnom Penh, Cambodia.*

[2] *Research and Innovation Center, Institute of Technology of Cambodia, Russian Federation Blvd., P.O. Box 86, Phnom Penh, Cambodia.*

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Abstract: *The Royal Government of Cambodia has set a target of providing clean water to the residents of the whole country in 2025, in which up to 90% of households are covered by piped water supply. To date, nearly 400 water supplier providers (formal and informal) are presented and reported that existing infrastructure reveals poorly designed systems and construction mistakes. The standard design for water supply and modern technology was proposed to improve the efficiency of the piped water system. Thus, this study aimed to standardize the design criteria for urban water supply in Cambodia relating to essential parameters. Firstly, to determine the flow pattern and peak flow coefficient of water consumption, and lastly, to evaluate the existing water supply system in the urban water supply system. The Anlong Romiet water supply represents a small-scale piped water system that was selected as the study area. This water supply was operated under the private sector, which has a capacity of 1900 m^3/day and serves a total area of 15 km^2 in two communes. The observed flowrate data from 2019 to 2021 and end-piped residual pressure were collected. A hydraulic model, the EPANET software, was used to stimulate the flow, produce residual pressure, and provide scenario projection to improve the piped network. The model calibration and validation of end-piped residual pressure were satisfied with an R^2 of 0.84 and 0.78, respectively. This research found that the average peak flow coefficient was approximately 1.5 ± 0.1, typically used in the urban water supply. While peak hour demand was observed two times in the morning, from 7 to 8 am and in the evening from 5 to 6 pm. The current study's highest frequency value of average nodal pressure was 30 m. The analysis revealed that current water demand is steady in terms of end-pipe pressure; however, dramatically low water pressure (under 5 m) will occur in 2035.*

Keywords: Piped-water supply; Flow pattern; Water consumption; EPANET; Peak flow

1. INTRODUCTION

Water supply networks are significant to delivering sustainable development goals (SDGs) in Cambodia by safely managing and providing good drinking water services. The indicator of this goal is the proportion of the population using safely managed drink water services, which requires drinking water services to be on-premises, available when needed, and free from microbiological and priority chemical contamination [1]. A well-maintained piped-water network is crucial to delivering drinking water services that meet safely managed standards. In 2015, there were an estimated 300 privately managed water supply schemes in rural Cambodia, serving over one million people [2]. However, in 2017, only 26% of Cambodians had access to safe drinking water services from the government and privately managed schemes [3]. Later, Cambodia allowed private companies to get a license to provide piped treated water services to most parts of the country, and as a result, the majority of piped water suppliers are private, amounting to over 400 companies [4]. Sources of water consumption were categorized as wells, ponds, lakes, streams, and rivers. The water supply capacity varied from 300 to 9600 m^3/day. Their water charges ranged from 2000 to 2500 riels per cubic meter [5].

Generally, the water supply networks are included in the master plan for communities, municipalities, and countries.

* Corresponding author: Davin Sang
E-mail: sang.davin@itc.edu.kh; Tel: +855-18 844 984

Their planning and design require the expertise of city planners and civil engineers, who must consider many factors, such as location, current demand, future growth, leakage, pressure, pipe size, pressure loss, firefighting flows, etc. The water supply systems get water from various locations, including groundwater and surface water (lakes and rivers). The water is then, in most cases, purified and disinfected through chlorination. Treated water flows by gravity or is pumped to reservoirs that can be elevated, such as water towers or on the ground. The water is then fed into distribution systems [6].

In Cambodia, the small-scale piped-water system delivered by enterprises is connected directly to people's houses or near their houses and fitted with a water meter. The water is used primarily for domestic usage and may or may not be used for drinking, depending on the choice of the household [7]. However, previous studies found that the infrastructure, water quality, and service standards of private water operators in Cambodia were inadequately regulated, had limited staff capabilities and technical expertise, and struggled to access capital for service improvements and expansion [2,8]. The customers usually face water intermittently for those who live near the end of the pipe water supply. Water availability affects the frequency of water and can also vary according to season. For example, in Phnom Penh, Cambodia, it was observed that the continuous operation of the water supply was interrupted during the wet season due to frequent filter backwashing and the need for basin cleaning [9]. The pressure deficient conditions are inevitable in water distribution systems (WDSs). A 'too low' pressure head would not be acceptable and could result in numerous customer complaints. In addition, it could lead to operation and maintenance problems, with cost implications if the equipment is damaged (e.g. pipe collapse due to negative pressure) [10-12]. The primary purpose of the water distribution network is to supply water at adequate pressure and flow in the performance of urban areas and to provide potable quality water to the consumers [13].

Thus, the piped-water system should follow the Ministry of Industrial and Handicraft (MIH). However, private investors must invest with their own financial sources, and they usually face difficulty deciding how large the infrastructures they should support, such as water production facilities, pipe networks, etc. Thus, the Anlong Romiet water supply, which represents the small-scale piped water system, was selected as the study area of this project. The reliability assessment of the water distribution network needs to look through many factors such as demand variables through the condition of the network, the pressure with flow relationship of water consumption, etc. Thus, this study aimed to determine local-based design parameters for water production facilities and pipe networks to efficiently improve water supply capacity. The local-based parameters such as the water consumption pattern, peak flow coefficient, service quality of pipe water, and infrastructure were also determined.

2. METHODOLOGY

2.1 Study area and data collection

The study area was conducted in the Kandal Stueng district (see Fig.1), including Along Romiet and Baku communes. The number of households in Baku and Anlong Romiet was 1286 and 994, respectively. The number of populations was 6300 people in Baku and 4268 people in Anlong Romiet, as reported by NCDD [14]. The existing water treatment plant (WTP) is located Along Romiet. The Anlong Romiet water supply was selected as the study area because it represents the small-scale private water supply. In addition, there is sufficient data recorded, which could be the potential for our project. The water supply could provide approximately 1900 m^3/day and serve a total of 15 km^2 in these two communes of the Kandal Stueng district.

The water is distributed into the main pipeline by pumps at the pumping station; then, the water flows from the main pipeline to the service pipeline and then to customers. The available data obtained from the water supply are illustrated in Table 1 and Table 2. The flowrate data was hourly recorded by a flow meter installed at the water treatment plant (2019-2021). The data of end-piped pressure was directly measured at the user household that was closed to the end-piped location by pressure gauge (see Table 2). The existing water distribution network was re-drawing by using google earth. Nodal elevation was taken from topographic data U.S geological survey science with 30 m full resolution. To ensure the accuracy of this data, nodal elevation was verified with google earth pro, and the procedure was described in El-Ashmawy [15]. The pipe network consists of 32-315 mm diameter pipes connected to an extensive water piping network. The entire distribution network consists of 255 pipes with the same materials and 249 junctions (nodes).

2.2 Model setup and processing

A hydraulic model, the EPANET model, was set up as a tool for understanding the pipe network distribution in this study. The model was used to simulate the flow and residual pressure of the water pipe network. The Darcy-Weisbach method [16] was used to calculate the head loss on surface resistance given by the Darcy-Weisbach equation.

$$h_f = \frac{fLV^2}{2gD} \qquad \text{(Eq. 1)}$$

Where L = the pipe length and f = coefficient of surface resistance, traditionally known as friction factor. Eliminating V, the following equation is obtained:

$$h_f = \frac{8fLQ^2}{\pi^2 gD^5} \qquad \text{(Eq. 2)}$$

The coefficient of surface resistance for turbulent flow depends on the average height of roughness projection, ε, of the pipe wall.

The average roughness of pipe walls for commercial pipes is listed in Table 3. The overall procedure is demonstrated in Fig.2. The input data such as population, node elevation, and water distribution network were first conducted in QGIS. After checking the accuracy, these data were plugged into EPANET. The necessary data, such as the dimension of tanks, pipes, and pumps, were input into the model. The simulation was done then the results were calibrated and validated to reach the satisfaction value. The flow and residual pressure observations were collected directly from the water supply system.

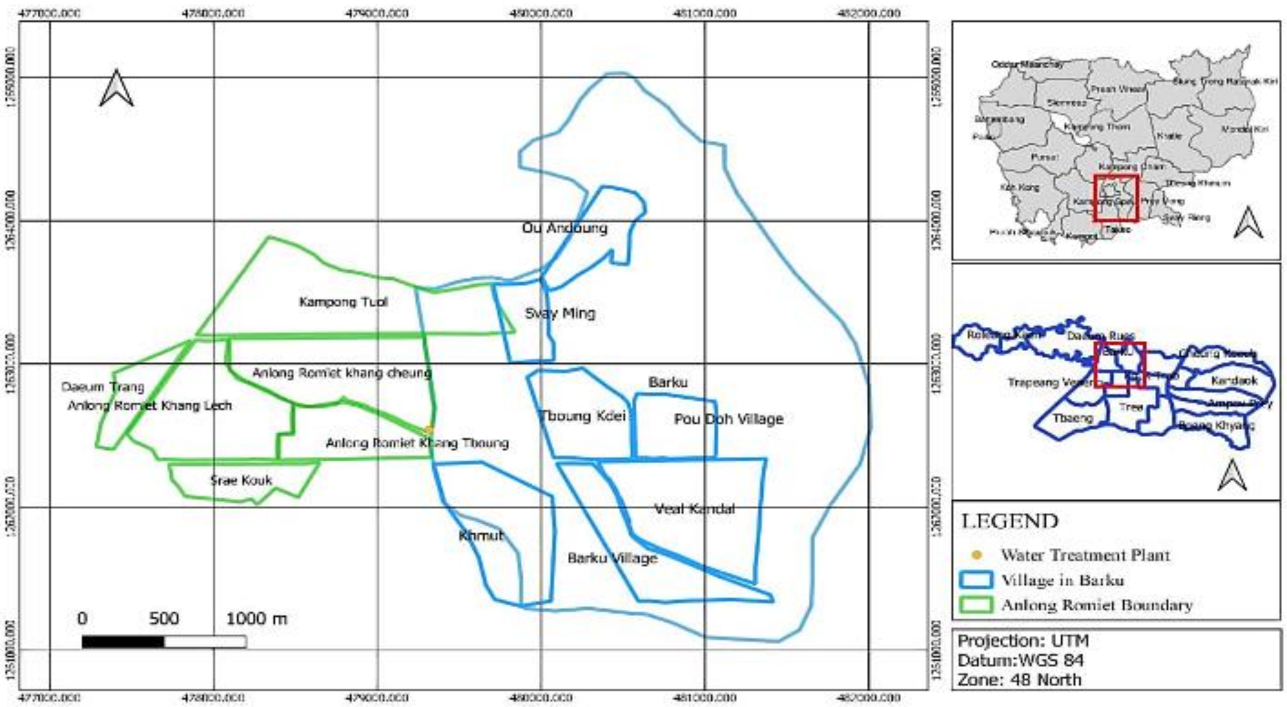

Fig. 1. Map of study and water distribution system of Anlong Romiet water supply

Table 1 The observed flowrate at Anlong Romiet water supply (ARWS 2019-2021 data)

Flowate	Unit	Nov-Dec 2019	Jan-Dec 2020	Jan-June 2021
Q_{annual}	m^3/y	86,240	587,124	284,942
$Q_{avg,daily}$	m^3/d	1,437	1,609	1,583
$Q_{max,daily}$	m^3/d	1,610	1,955	2,058

Table 2 End-piped pressure data

Location	Pressure (m)[a]	Pressure (m)[b]
J104/RP-5	7.35 ± 0.40	7.23 ± 0.15
J65/RP-7	16.76 ± 0.38	19.33 ± 1.06
J28/RP-4	16.73 ± 0.40	21.13 ± 0.21
J60/RP-1	20.70 ± 0.70	20.70 ± 0.70
J87/RP-2	26.43 ± 0.40	27.20 ± 0.69
J95/RP-3	25.51 ± 0.69	27.14 ± 0.82
J76/RP-6	16.73 ± 0.40	20.08 ± 0.52

[a] data used for calibration, [b] data used for validation

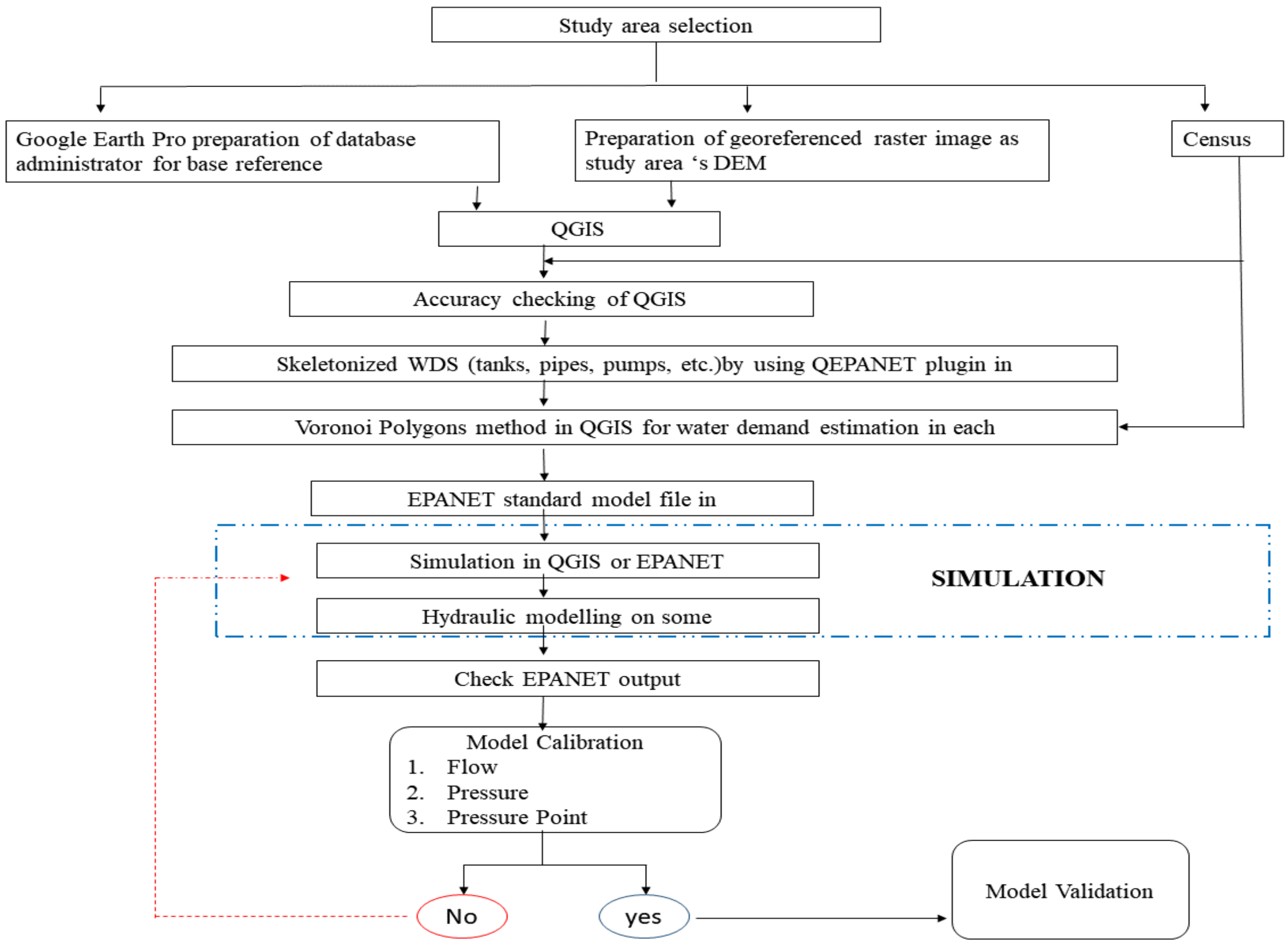

Fig. 2. Methodology flow chart

Table 3 Average roughness [16]

Pipe material	Roughness height (mm)
Wrought iron	0.04
Asbestos cement	0.05
Polyvinyl chloride	0.05
Steel	0.05
Asphalted cast iron	0.13
Galvanized iron	0.15
Cast/ductile iron	0.25
Concrete	0.3 to 3.0
Riveted steel	0.9 to 9.0

3. RESULTS AND DISCUSSION

3.1 Water consumption pattern and peak coefficient

Peak water demand has a vital role in water distribution system design because it represents one of the most onerous operating states of the network. Thus, the available hourly data recorded was used to analyse to determine the consumption pattern and peak coefficient in this study area.

3.1.1 Water consumption pattern

The average hourly flow pattern is illustrated in Fig.3. Based on this observation data, it was observed that the highest water demand was found in the dry season, generally from March to May every year for this study area. The highest water demand could be influenced by people's behaviour regarding water usage. Typically, people prefer to save and store rainwater as the primary wet-season drinking water supply for approximately 60% of rural households [17]. Most households with poor accessibility obtain their water from distant surface water sources in the dry season. Water demand is also variable during the year, as can be seen from Fig.3, which shows relatively the average hourly flow rates were slightly increased in 2021 due to the increase in consumers and the enlarged capacity of the water treatment plant. Overall, the average water demand for this study area was 80 m^3/h, corresponding to approximately 147 L/day per capita. This finding was similar to the minimum water quantity (150 L/day per capita) recommended by the World Health Organization (WHO).

Regarding peak hour of water demand illustrated in Fig.4, it occurred two times, in the morning from 7 to 8 am and in the evening from 5 to 6 pm, which is different from urban areas like Phnom Penh city, there is only peak hour in the morning, 6.00 to 8.00 am [18]. The maximum water demand during a day is a complex phenomenon influenced by climate, socioeconomic aspects, cultural habits, water supply policies, pricing policies.

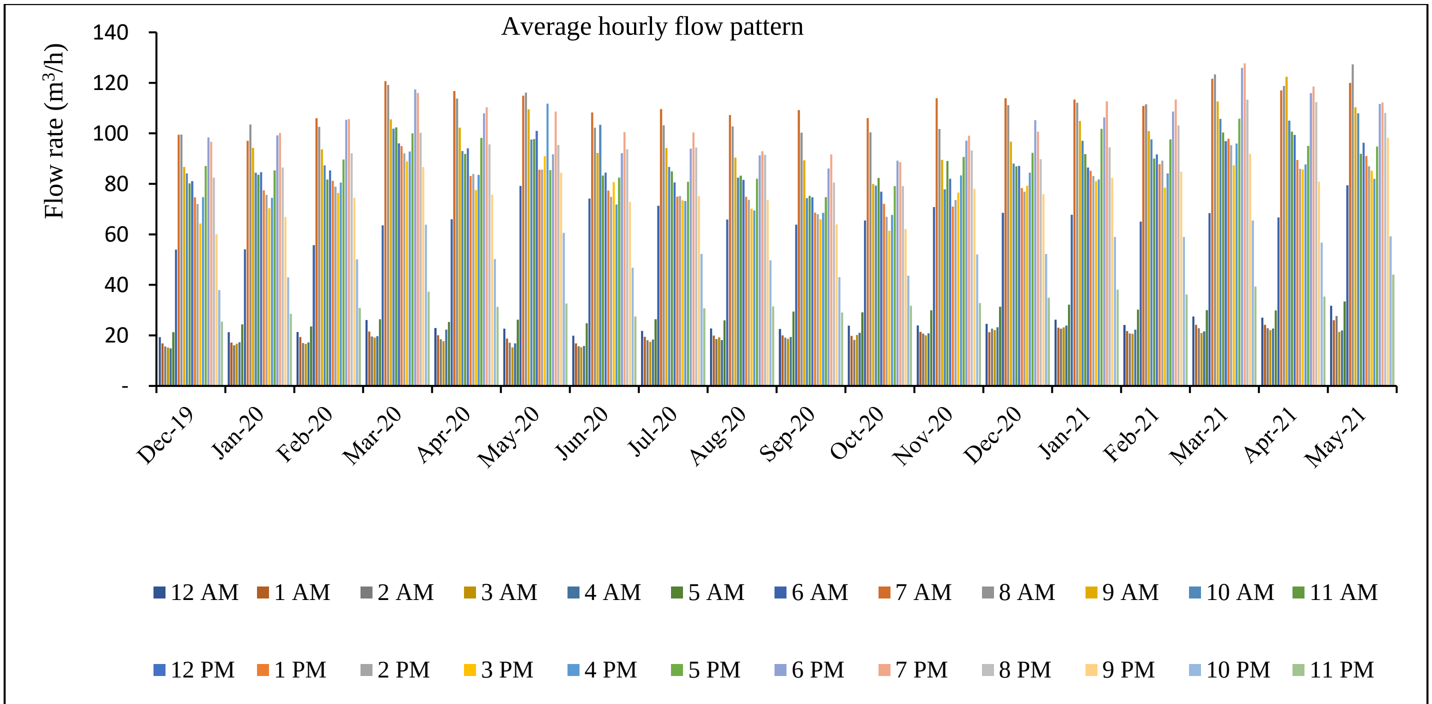

Fig. 3. The average hourly flow pattern

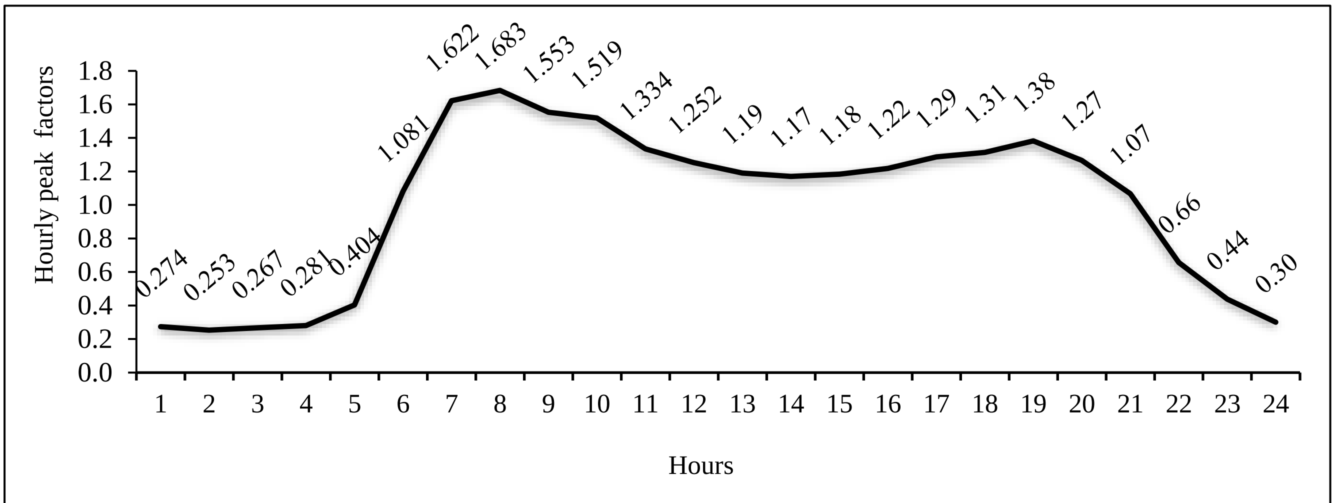

Fig. 4. Peak coefficient

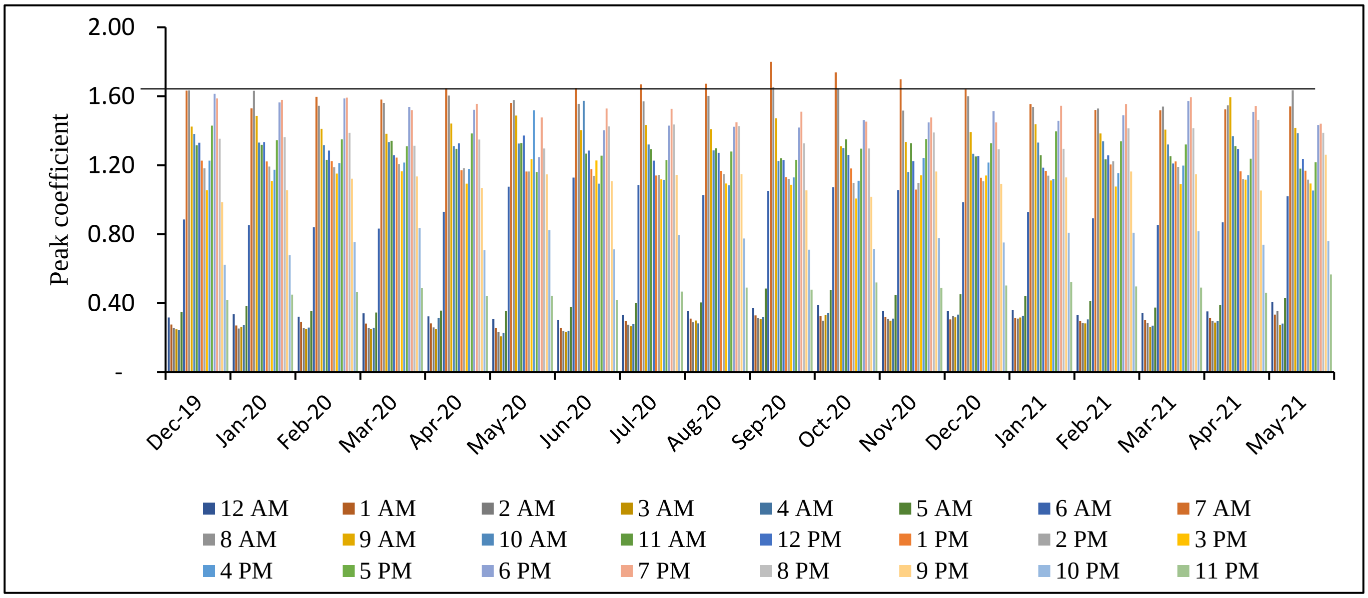

Fig. 5. Peak coefficient of hourly demand

3.1.2 Peak coefficient

The maximum hourly peak coefficients extracted from the observed dataset were used to investigate and assess the stochastic behaviour of the peak water demand at the local scale. In general, the value of the hourly peak factor is related to the number of water consumers or the amount of total water demand; the larger the number of consumers or larger water demand gives a smaller hourly peak factor. The hourly peak factor is demonstrated in Fig.5. The result found that the hourly peak factor in this study area was an average value of 1.5 ± 0.1. An hourly peak factor of 1.5-3.0 is typically used on urban water supply projects [19] . The peak coefficient is usually higher in small communities than in large ones, while in very large centres, water demand tends to be constant in time and close to its average [20]. The peak factor is usually assumed to increase when the decreasing number of consumers, as reported in Johnson [21].

3.2 Model calibration and validation

The model calibration and validation of end-pipe pressure were conducted. The observation data of end-pipe pressure was primarily measured using pressure gauge monitoring devices at the selected location. The calibration and validation of end-piped pressure between simulation and observation data were obtained at good correlation, R^2=0.84 (Fig.6) and R^2=0.78 (Fig.7), respectively. The variation in end-pipe pressure and simulation are illustrated in Fig.8.

3.3 Nodal pressure under actual demand

Nodal pressure was classified into five classes according to its frequency (Fig.9). The highest frequency value of average nodal pressure was 30 m. The overall pipe-water system has higher pressure than 10 m at almost every point, except that road 20A intersects with national road 3; both observation and simulation were under 10 m. Based on this finding, the current situation of this water supply system could be assumed that consumers have sufficient water needed and do not have any problems at the present time, so this proof complies with the response from the water supply facilitator.

3.4 Nodal pressure under projection in 2035

The current population of this study area was approximately 12,984 people in 2021, calculated from the number of households counting from google earth multiple by average people in each house (4.6 persons) [22]. However, the growth rate of Kandal province was assumed to be a 2.93% [23] increase in 15 years (2035). The water demand was assumed as 150 L/day, which is the minimum water quantity recommended by WHO. The detail of population and water demand estimation in 2035 were determined. The projection of nodal pressure was simulated. The contour plot of the pressure variable represents the number of resources available, which indicates how far the state variable was from its limit value. The pressure map showed the slack of each element for the current study and, in 2035, was demonstrated in Fig.10a and Fig.10b. The slack map can be used to choose preferable points for future network expansions, initiating the selection process by the nodes with more significant slack. As seen in Fig.10b, the nodal pressure dropped significantly below 10 m. The system must be reconsidered. The pump curve should be improved by at least 60 m with the same pump discharge of 46 L/s (2 pumps). The average water demand was approximately 60 L/s which should be applied to Anlong

Romiet water supply to balance supply and demand by 2035. The unit supply must be improved the water treatment plant capacity and look for new sources to imply the goal.

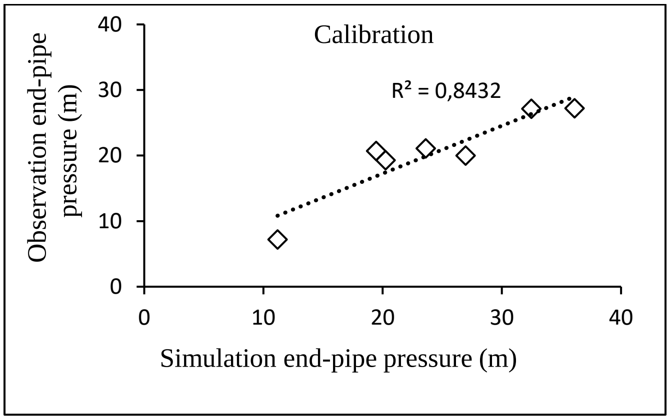

Fig. 6. End-piped pressure of model calibration

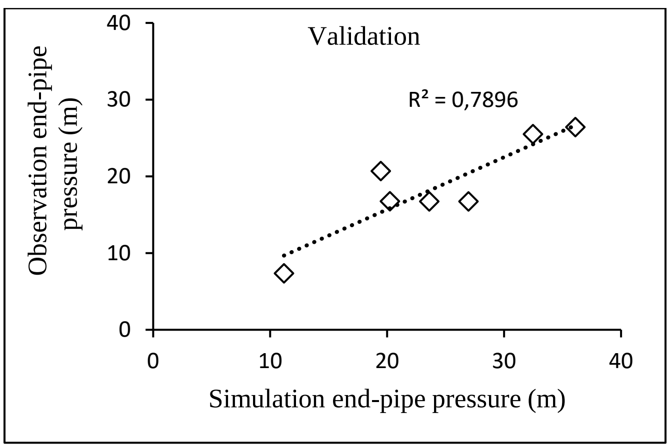

Fig. 7. End-piped pressure of model validation

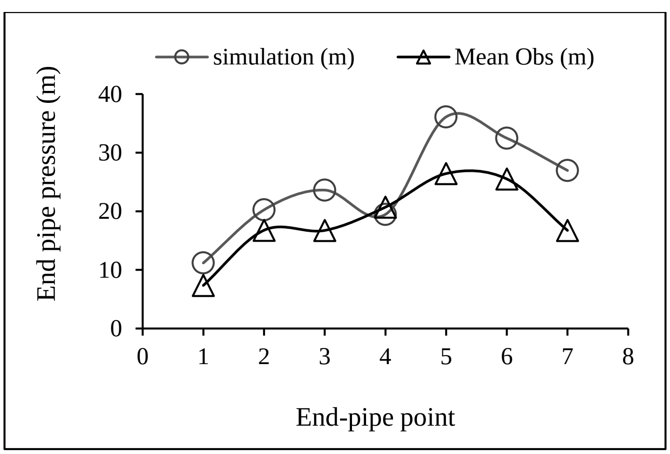

Fig. 8. End-piped pressure simulation versus observation

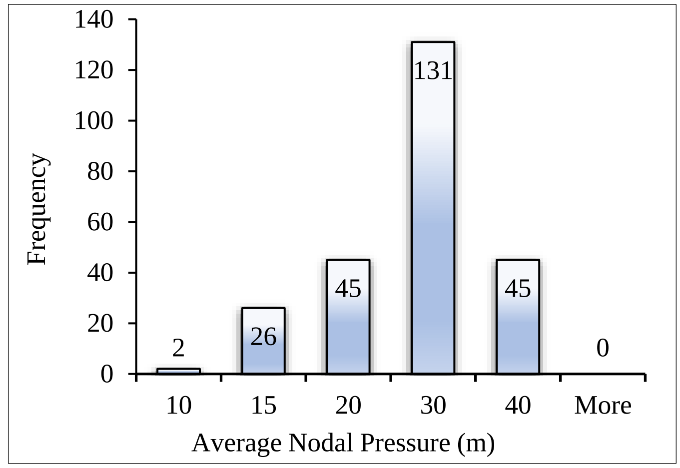

Fig. 9. Frequency of average nodal pressure

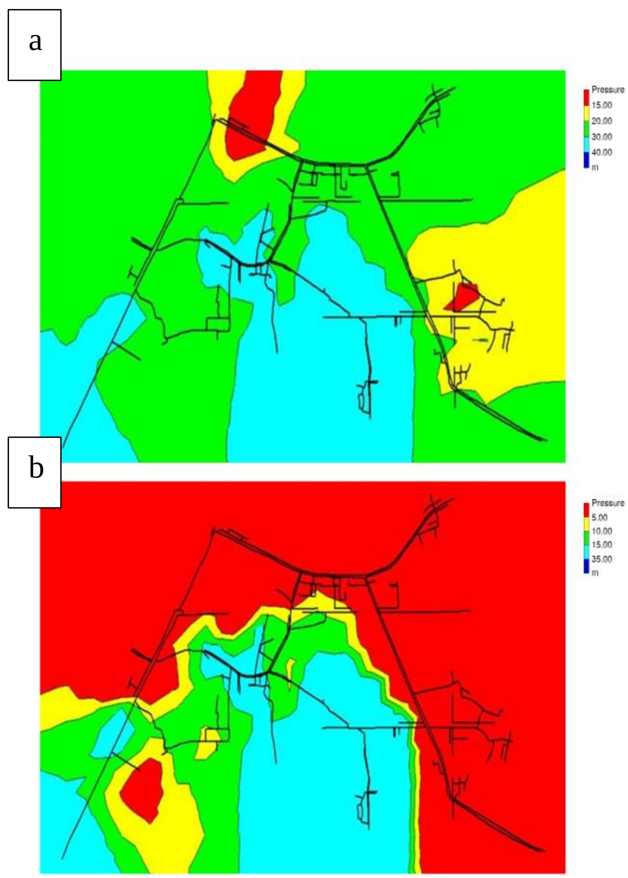

Fig. 10. Contour plot at current state (a) and projection of pressure (b) at 8:00 am

4. CONCLUSIONS

In this study, instantaneous flow data of water consumption were exploited, collected from the two communes' location d Kandal Stueng as expected; an analysis of the years and a half data revealed the existence of patterns in which it is possible to identify daily periodicities in hourly water demands as well as weekly periodicities in daily water demands. Based on this observation data, it was observed that the highest water demand was found in the dry season, generally in March, April, and May every year for this study area. The average water demand for this study area was 80 m^3/h, corresponding to approximately 147 L/day per capita. Regarding the peak hour of water demand, it occurred two times, in the morning from 7 to 8 am and from 5 to 6 pm. Moreover, the result found that the hourly peak factor in this study area was an average value of 1.5 ± 0.1. Currently, the overall pipe-water system has higher pressure than 10 m at almost every point, except the point along road 20A intersects with national road 3; both observation and simulation were under 10 m. However, the pressure was dramatically low (under 5 m) in projection 2035. In brief, the peak coefficient and flow pattern should be used for the peri-urban or the site with a similar characteristic for designing the capacity of WTP, pipe network, and selecting an appropriate pump. Other water supply stations, such as provincial towns and rural areas, should record the hourly flow data to provide separate peak coefficients and flow patterns. Further research should be conducted more broadly to produce several peak coefficients and consumption patterns following the different site characteristics such as urban, peri-urban, rural, industrial area, etc.

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