10th WaQuAC-NET Webinar

A Study on Non-Revenue Water Reduction -Theory and A Case Study in Phnom Penh City Capital of Cambodia

Phnom Penh Water Supply Authority (PPWSA)

Present by: CHENDA Pharith

Date: 2022.April.30

Conten
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- Introduction
- Descriptive of Study Area
- Literature Reviews
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- Conclusion and Recommendation

Background

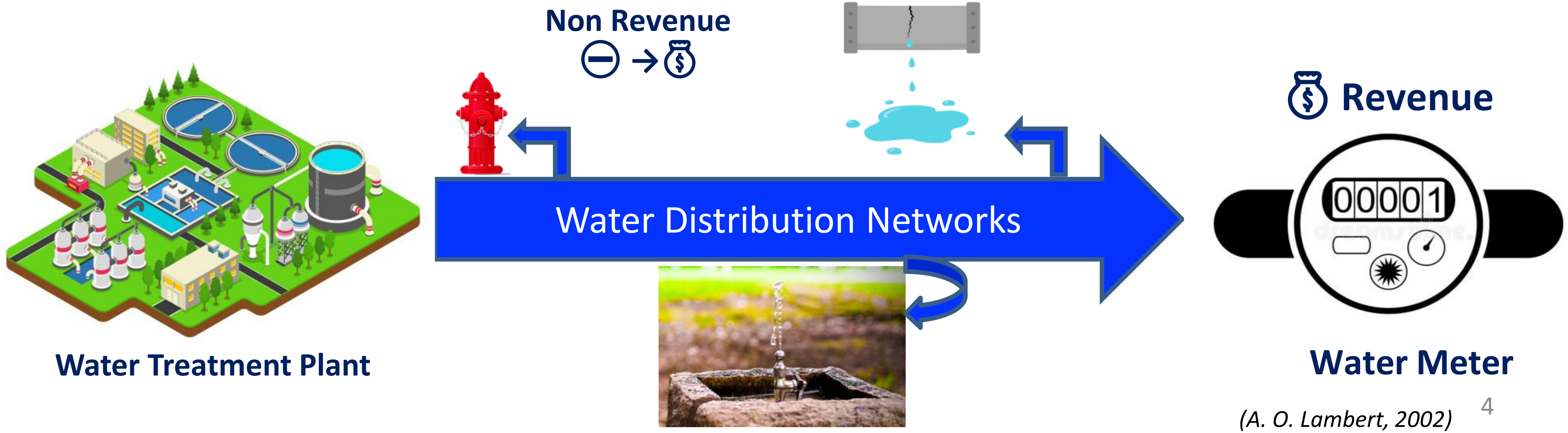
ចិន្ដា ផារិទ្ធិ CHENDA Pharith

- Graduate Engineering degree of Water Resource and Infrastructure Rural from Institute of Technology of Cambodia(ITC) in 2016
- Working for Phnom Penh Water Supply Authority Since 2016
  - Input Leakages Data into GIS system
  - Monitoring Flowrate and Pressure for the entire supply area
  - Monitor leakage Repairing Facilities
  - Pressure monitoring
  - Prepare report and meeting slide for management team
- Master's Degree of Regional Development Studies from Toyo University, Tokyo, Japan in 2021.
- Current Position: Chief of Section of Water Loss Detection office in Distribution Department, Phnom Penh Water Supply Authority(PPWSA).

Introduction

Definition of Non-Revenue Water(NRW)

* **NRW** is the difference between the amount of water input to the system and the amount of water billed to customers. Such losses are mainly cause by leakages, illegal connections and metering in accuracies.



(A. O. Lambert, 2002)

Introduction

- **NRW** consist 3 components
  - Physical Loss
  - Apparent loss
  - Unbilled Authorized Consumption

Taken during Research field trip in January 2021

- **NRW** could not eliminated in all of water utilities, however; it can minimize to suitable level.

- **Reducing NRW will offer 2 benefits in general :**
  - Increase the revenue for water utilities
  - Save the water for environmental aspects

(A. O. Lambert, 2002)

Background and Problem Statement

Most Developing Countries

- ✯ Rapid Urbanization
- ✯ Economic Development
- ✯ Population Growth

→

- ☆ Expanding Water Network
- ☆ Increasing Water Demand
- ☆ Limited Raw Water Source

Phnom Penh Water Supply Authority Case

- ✯ More than 30 years-old of water facilities is still using in city center
- ✯ Water shortage occur cause by limited Water Treatment Plant
- ✯ Non-Revenue Water has been increasing for the last few years
- ✯ Approximately 5.5 Million USD estimated to be lost equivalent to 18 Million m^3 in 2019

Research objectives

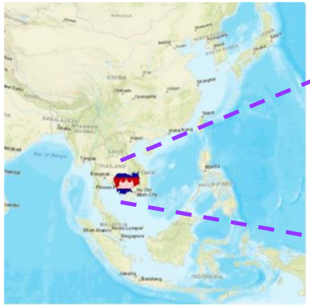
The overall purposes of this research are to contribute to policy maker of PPWSA in term of NRW reduction. The Specific objective are below:

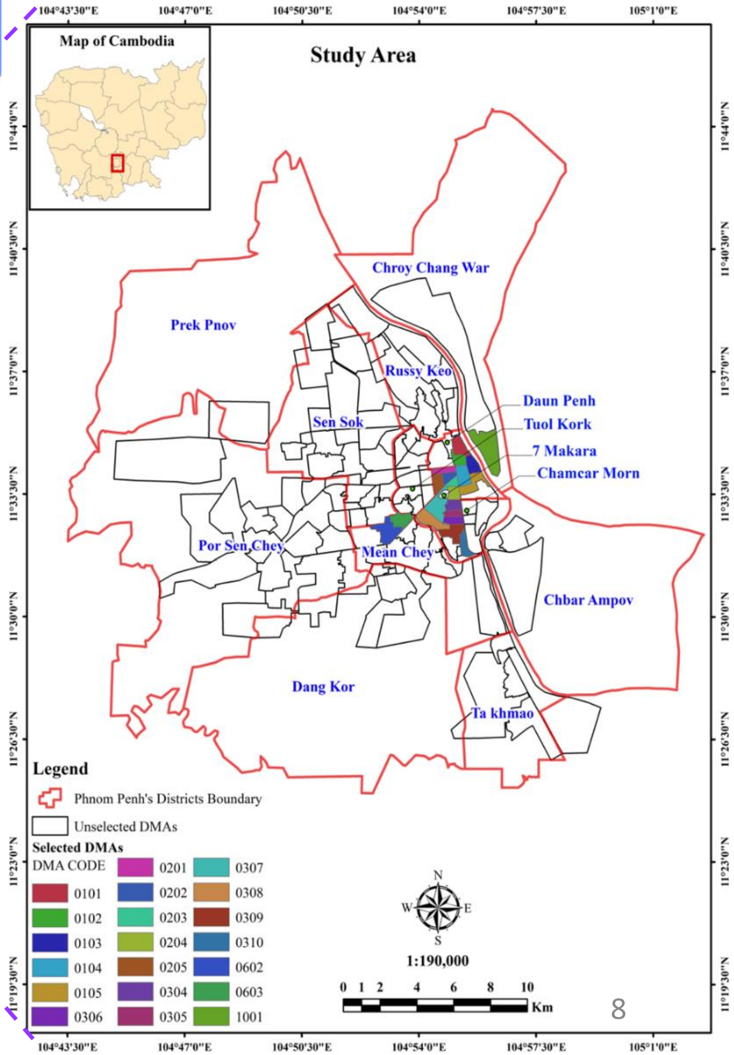
1. Identify the **Most Affecting Factor** which influence on increasing **Non-Revenue Water Ratio.**
2. Propose **Priority Counter Measures** for reducing Non-Revenue Water in direct and indirect method.

Research Hypotheses

1. Deteriorated pipe caused by aging pipe could cause the leakages which influence NRW ratio increasing.
2. More dense of water meter in a kilometer could lead meter inaccuracy, longer serviced pipe which drive NRW ratio up. Pressure management could be one of the indirect method reduce water loss and extend life of facilities.

Description of the Study Area



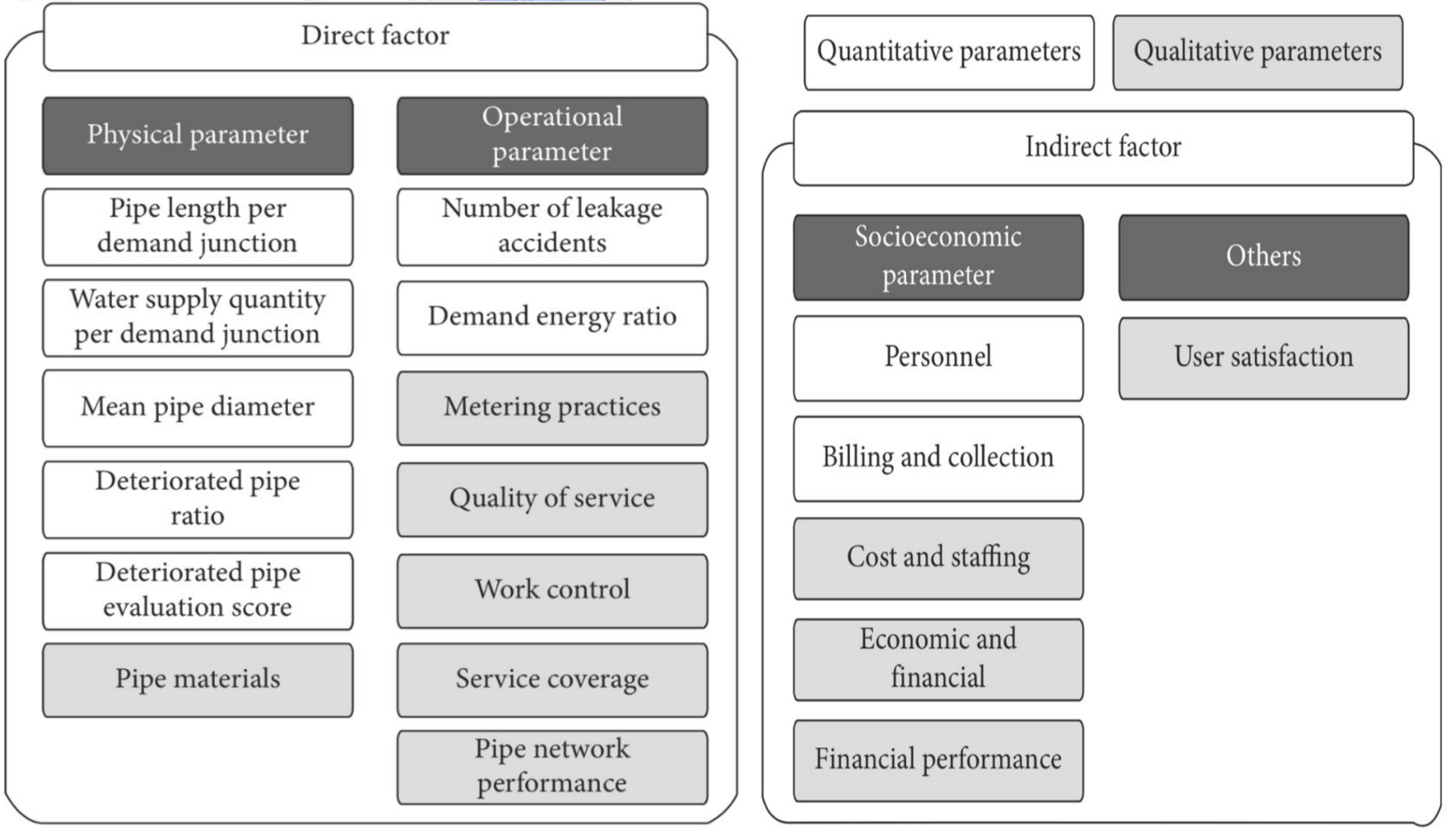


- ✯ District Metering Area(DMA): 20 DMAs (located in the city center)
- ✯ Customers connections: 66,570 meters
- ✯ Total Pipe Length: 331km
- ✯ Total Water input: 18,734,643 m^3
- ✯ Average Water Supply: 4,351m^3/h

(PPWSA, 2020)

Literature Reviews

- ✯ Direct Factor and Indirect Factor.
  - ❖ Physical Parameter
  - ❖ Operational Parameter
  - ❖ Socioeconomic parameter
  - ❖ Others



(Dongwoo Jang et al., 2018)

Literature Reviews

- ✯ These are the factors effecting on each component of NRW.
- ✯ Not all of these factor are available on every DMA

Physical Losses	Commercial Losses	Unbilled Authorized Consumption
◎ **Pipes breaks and leaks on mains, service reservoir and service connections** ◎ **Pipe length** ◎ Pipe Diameter ◎ **Pipe age** ◎ Pipe material ◎ Pipe thickness ◎ Water quality ◎ Water quantity ◎ **Pressure in the networks** ◎ **Flow rate** ◎ **Leakages Frequency** ◎ Depth of pipe installation ◎ Population growth rate ◎ Soil type ◎ Coating thickness ◎ **No of valves** ◎ Deteriorate pipe ratio ◎ Demand Energy ratio ◎ **House connection leakages** ◎ **Number of Service connection** ◎ Location of customer meters on service connections ◎ Construction sites	◎ Metering reading errors ◎ **Age of meter** ◎ Negligence meter ◎ Customer water bills ◎ Meter under-registration ◎ Quality of meter ◎ Durability of meter ◎ **Average Size of meter** ◎ Location of meter ◎ Sediment concentration ◎ Water quality ◎ Brand of meter ◎ Water theft ◎ No. of illegal connection ◎ Water prices ◎ Water accounting errors ◎ Consumption rate ◎ Customer water bills ◎ **No. of customers**	◎ Unbilled meter consumption ◎ **Water provide to institutions free of charge or metered consumption by the utility itself** ◎ **Unbilled unmetered consumption** ◎ **Irrigating public parks** ◎ Landscaping ◎ **Street cleaning** ◎ Frost protection ◎ Flushing of water mains and sewers ◎ **Firefighting**

Factors Affecting NRW's components (Jang et al., 2019)

Literature Review on Statistical Analysis in Water Loss Controlling

Regression Analysis

Check the correlation between variables

$$Y = b0 + b1\ X1 + b2\ X2 + \dots\dots\dots\dots\dots\dots\dots + bk\ Xk$$

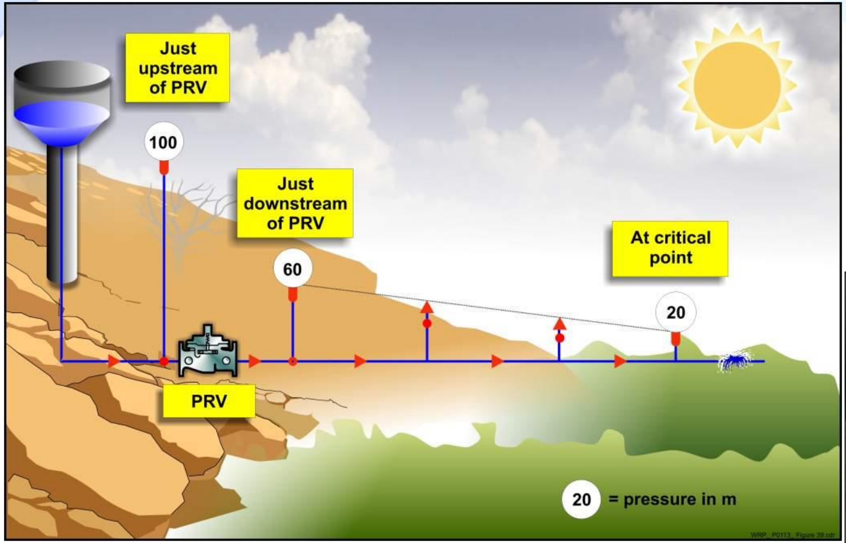
Principle Component Analysis

To omit unimportant factors in case of machine learning

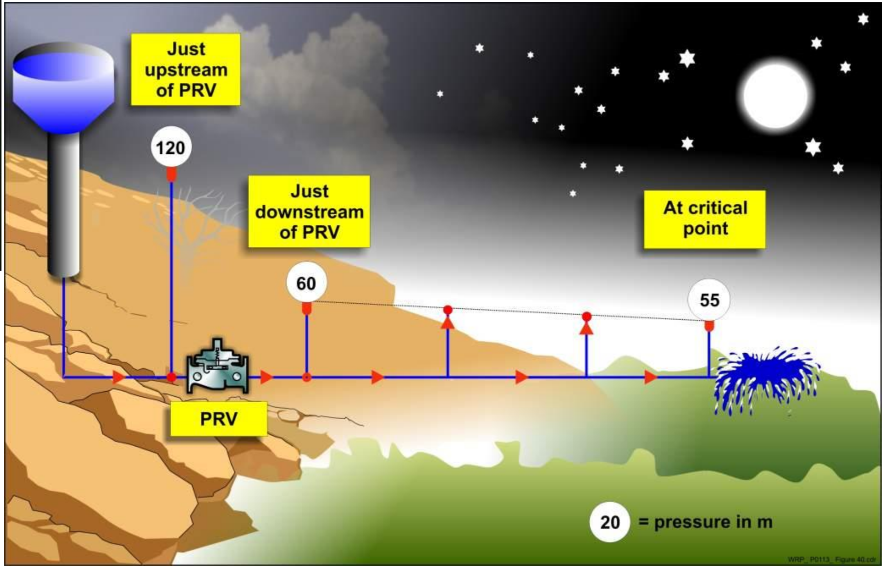
$$t_{k(i)} = x_{(i)} w_{(k)} \dots\dots\dots\dots\dots\dots$$

(Jang, 2018) & (Dongwoo Jang et al., 2018)

Introducing Pressure management



- Water loss is function with pressure.
- The high pressure at the point of leakages, the more water losses.
- Management for pressure is one of the most important measures for NRW reduction.



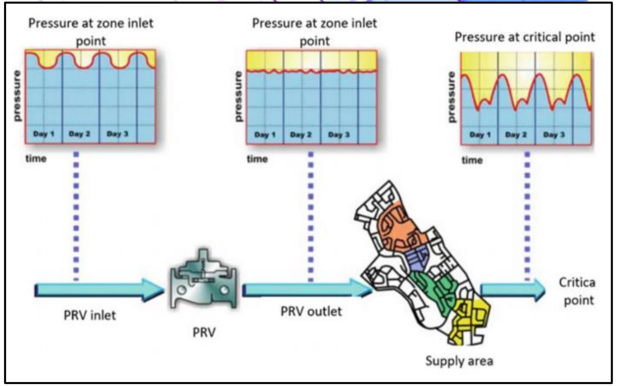
Concept of pressure management.

Source =Samir et al., 2017

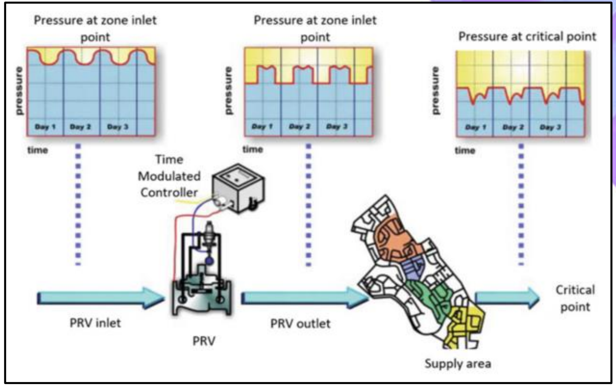
Literature Reviews on Pressure Control

✫ There are 4 different types of pressure management:

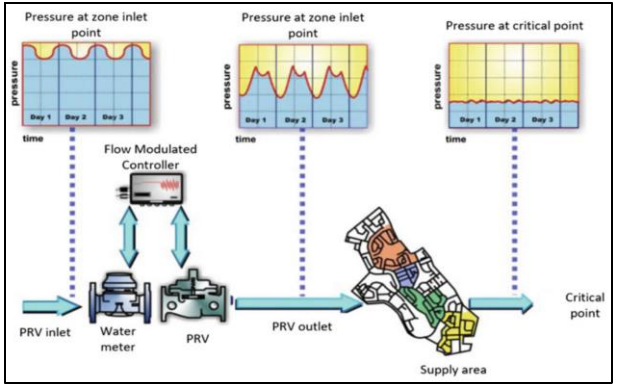
- Fixed Control Pressure
- Timed-modulated Pressure control
- Flow-modulated Pressure control
- Closed-loop Pressure Control



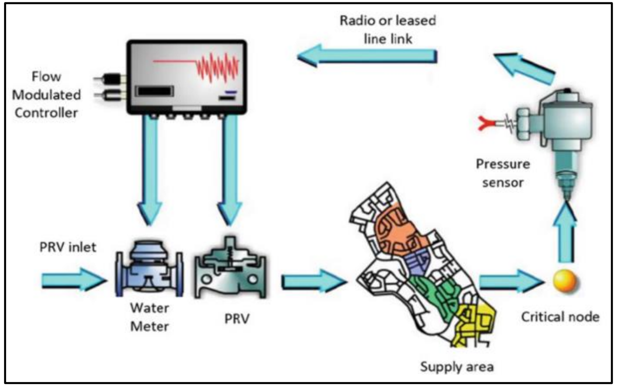
Fixed Control Pressure



Timed-modulated Pressure control



Flow–modulated Pressure Control



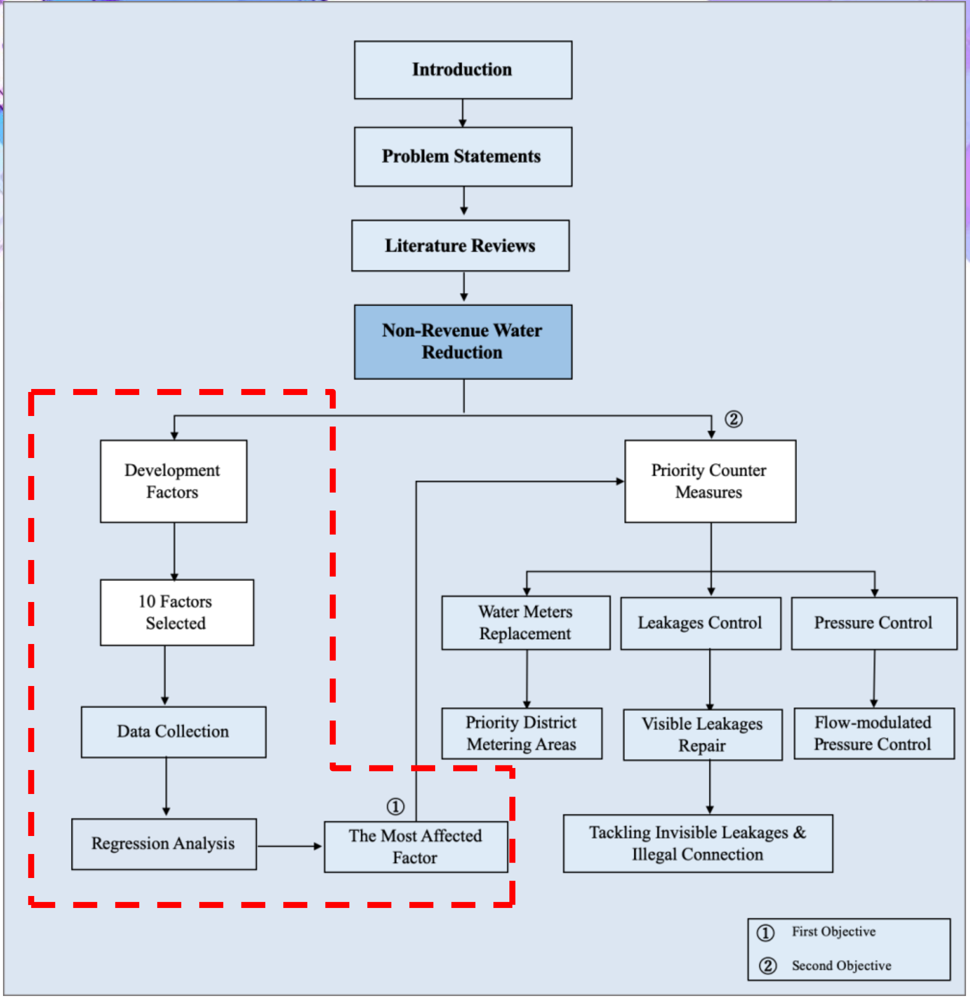
Closed-Loop Pressure Control

(Mckenzie & Wegelin, 2009)

Methodology

For the first objective:

- Select priority District Metering Areas(DMAs)
- Development factors effect on NRW ratio
- Secondary data collection
- Regression analysis to find the most effective variable.



Methodology (Continue)

- Linear Regression Model with an independent variable is expressed as following equation (Jang & Choi, 2017)

- **R program** is used for statistical analysis's tool for finding the most effected factor on the selected DMAs

- Y = b0 + b1 X1 + b2 X2 + ... + b20X20

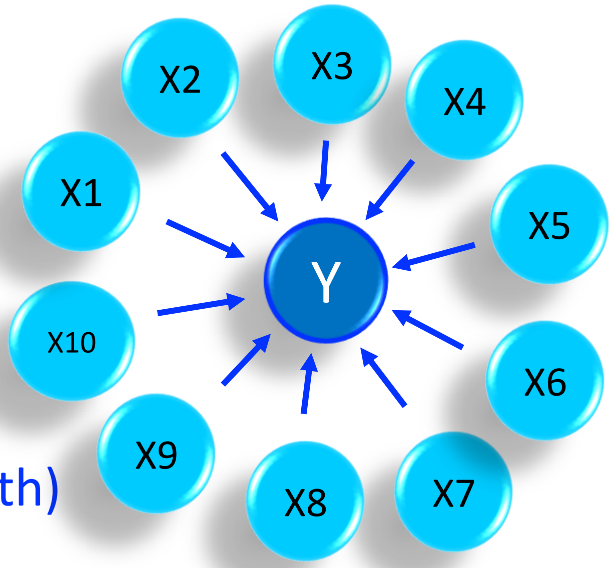
- Where Y is the independent variable, X is the dependent variable and b is the regression coefficients

Methodology (Continue)

Development Factors Effecting NRW Ratio

- **[Y] Non-Revenue Water Ratio of each DMA (%)**

1. [X1] Average Pipe Age (Month)
2. [X2] Average Flow Rate (m^3/h)
3. [X3] Average Pressure (m)
4. [X4] Average Meter Diameter (mm)
5. [X5] Average Age Water Meter (Month)
6. [X6] Total Pipe Length (Km)
7. [X7] Connection Density (Meters/a km pipe length)
8. [X8] Leakages Frequency (Times)
9. [X9] Valve Density Per Km^2(pcs/ Km^2)
10. [X10] Connection Density Per Km^2(pcs/ Km^2)



Methodology (Continue)

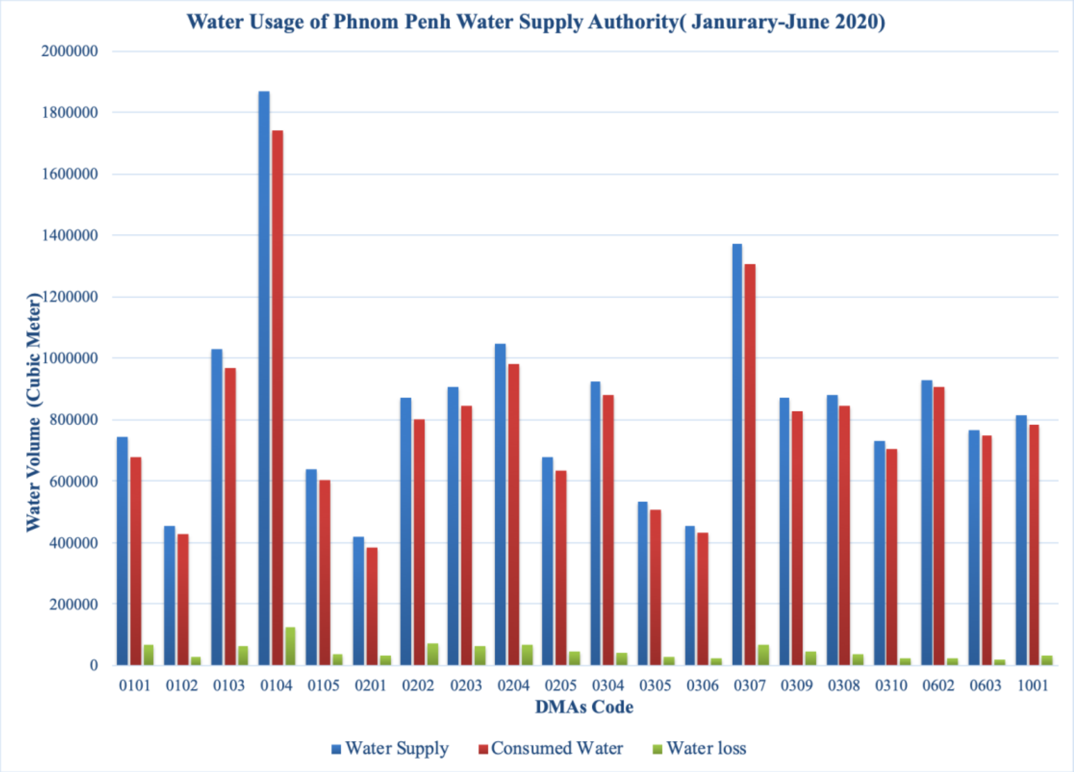
Data Collection

DMAs	(Y)	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
0101	**8.79**	**258**	**172.51**	**31.70**	**15.81**	**112.80**	**12.07**	**118**	**22**	**8**	**317**
0102	**6.28**	318	109.70	32.30	16.03	106.26	6.27	133	18	6	110
0103	**5.90**	294	240.91	42.90	15.52	96.08	12.68	139	10	13	984
0104	**6.74**	294	436.65	33.10	15.23	87.90	15.41	145	9	13	682
0105	**5.46**	294	164.86	32.60	15.55	92.20	13.67	139	4	9	388
0201	**8.12**	270	96.41	25.32	15.42	96.59	7.17	159	2	14	388
0202	**8.29**	270	200.15	32.50	15.30	95.38	9.06	175	15	20	1688
0203	**6.86**	270	213.34	33.00	15.28	86.91	8.30	159	25	21	2302
0204	**6.35**	270	240.06	33.00	15.59	95.23	10.05	145	4	22	683
0205	**6.54**	270	162.09	22.40	15.38	96.74	12.61	159	4	16	707
0304	**4.41**	270	241.63	35.40	15.18	92.20	11.49	123	14	19	670
0305	**4.84**	270	133.16	36.10	15.21	93.90	6.17	128	8	10	532
0306	**4.78**	246	106.49	35.10	15.22	93.36	6.67	127	1	8	459
0307	**4.89**	246	315.48	29.80	15.19	97.41	22.82	132	7	12	495
0308	**5.13**	258	222.23	34.30	15.48	85.17	18.42	133	11	10	333
0309	**4.21**	257	215.32	33.40	15.30	85.29	19.02	115	13	11	393
0310	**3.29**	258	166.05	35.60	15.45	91.92	8.28	112	25	8	297
0602	**2.46**	222	225.07	24.30	15.15	75.81	18.55	109	9	5	276
0603	**2.39**	210	175.68	30.00	15.14	75.20	14.81	105	11	7	473
1001	**3.97**	222	116.18	21.30	15.54	102.14	21.74	112	7	3	82

Methodology (Continue)

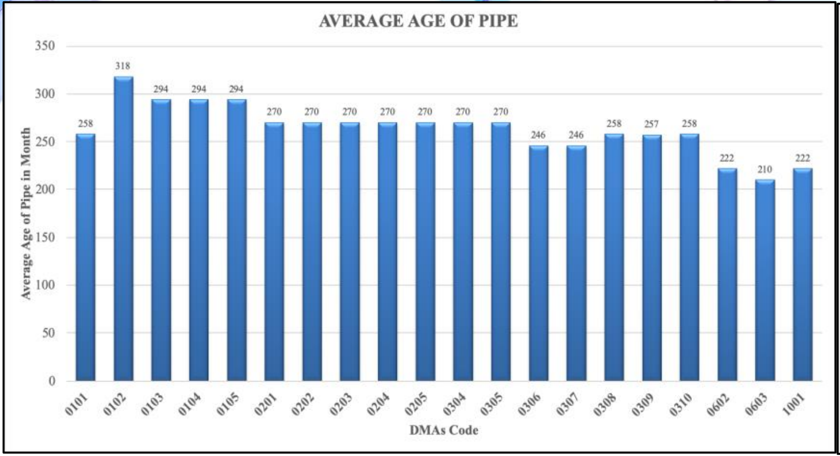
Data Analysis

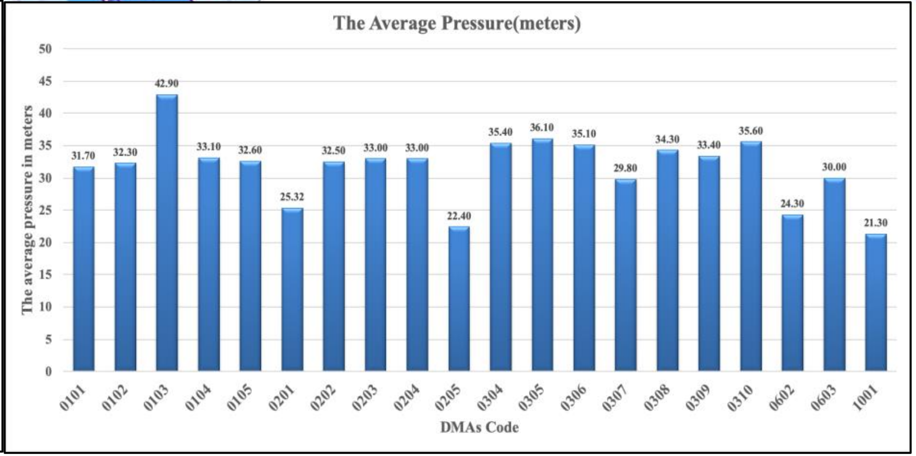
- ❖ The Figure shown about input water of each DMA, total water sold and water lost.
- ❖ These data was between January to June 2020.
- ❖ DMA code 0104 had highest consumptions, while DMA 0201 had the lowest one.
- ❖ The second high consumption could see in DMA 0307 which located in city center.
- ❖ DMA 0104 located in the city center, near the WTP and full of restaurants and apartments investment.

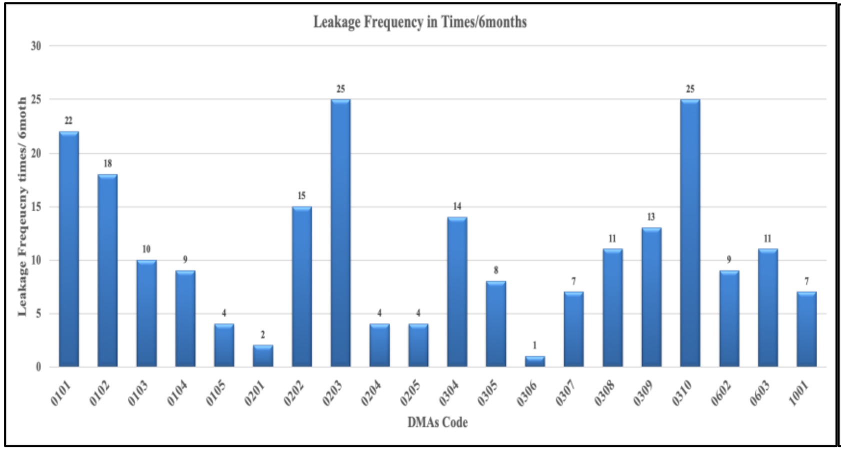


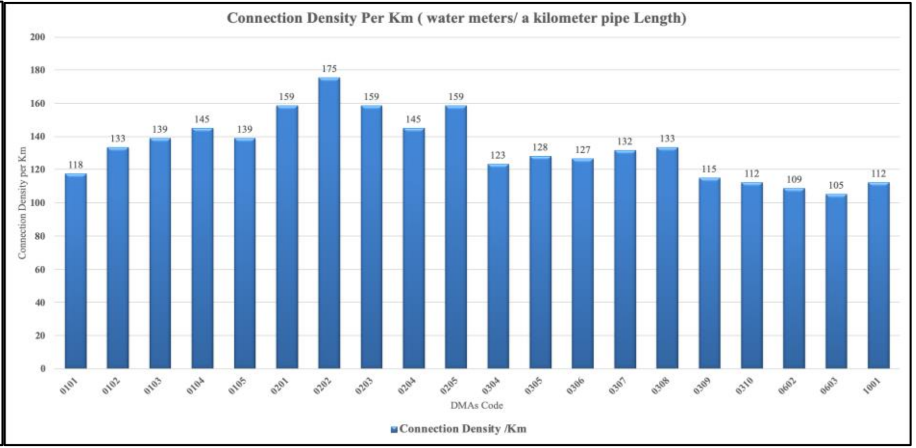
Methodology (Continue)

Data Analysis









Methodology (Continue)

- Leakage Frequency Index(LFI) Formula

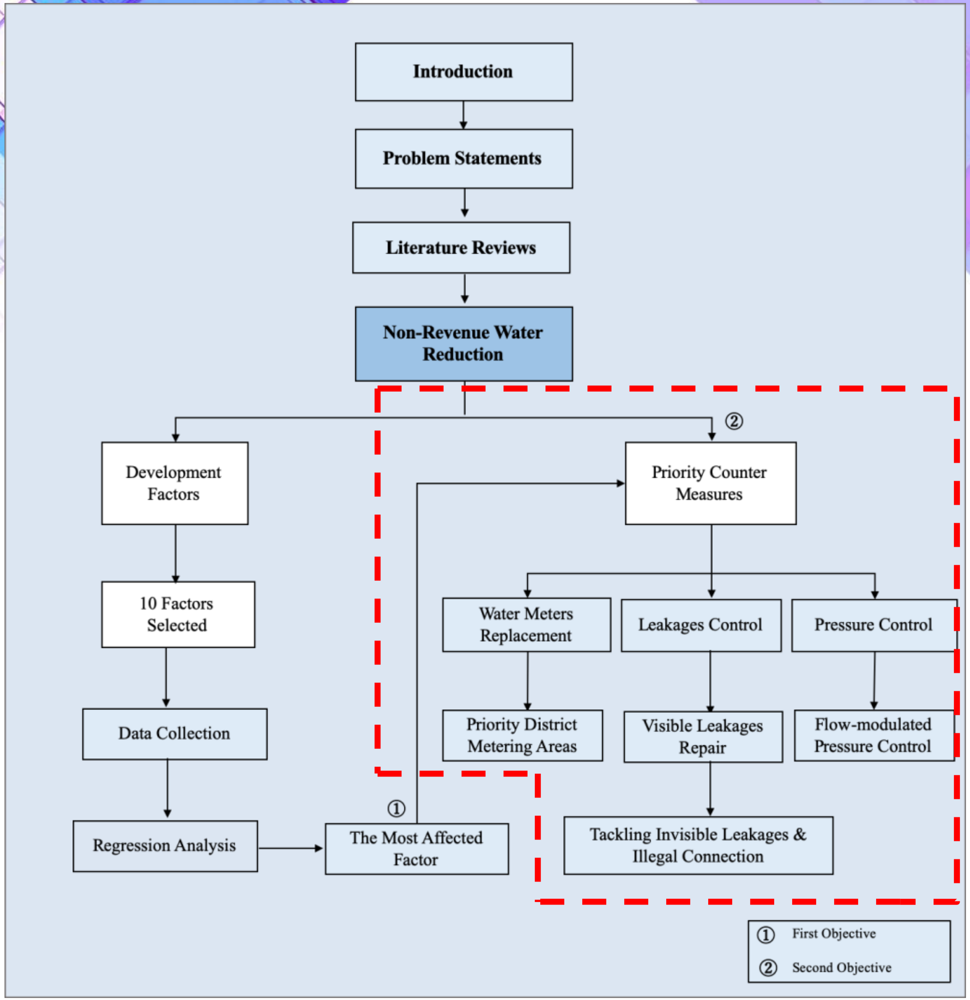
$$\textbf{Leakages Frequency Index(LFI)} = \frac{\textit{Leakage Frequency}}{\textit{Pipe Length}}$$

- Leakages Frequency Index(LFI) [Times/ 6month.km]
- Leakage Frequency [Times/6month]
- Pipe Length [Km]

Methodology (Continue)

For the Second objective:

- Replacement of water meter base first objective
- Focus on tackling leakages control (visible, invisible and illegal connection)
- Applying pressure control method by choosing Flow-modulated pressure control.



Methodology (Continue)

(JICA, 2008)

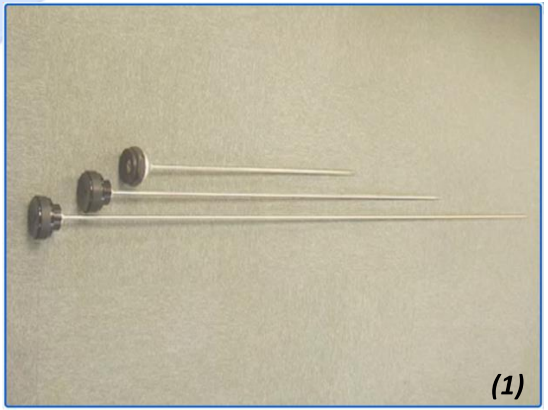

Taken during Research field trip in January 2021

Visible Leakages Control

- Base on Japanese experience, after world war II there are many ground leakages and **80% of water input** to the system was leaking away **in 1945**.
- Tokyo Metropolitan water work mobilized large number of officers and staff looking for leakages and repair it. Because of this widespread of emergency measure. Water leakages have been reduce to **30% in 1949** (JICA, 2008).
- This photo shown about leakages repairing during field observation in January 2021.
- More than **90% of leakage** occurrence were on **Serviced Pipe**.
- This direct and priority method have to be carry out efficiently.

Methodology (Continue)

Talking Underground Leakages



(1)

(2)

(3)

(4)

- ❖ There are 4 various equipment for detecting the leakages.
    1. Listening bar
    2. Electronic leak detector
    3. Time-integral leak detector
    4. Correlation leak detector
- ❖ All of these equipment's detecting on the sound of the leakage underground.
- ❖ Base on theory, it worked well with metal material like Ductile Iron(DI) Pipe and during the night time.

Source (JICA, 2008)

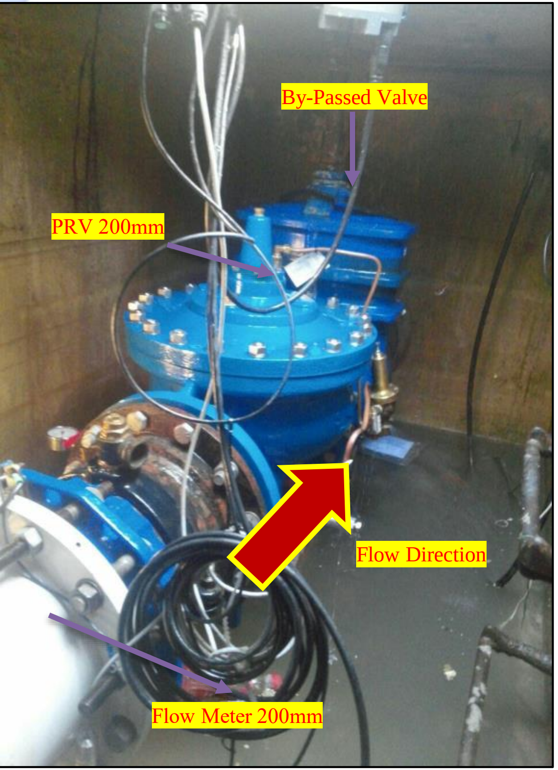
Methodology (Continue)

Takling Underground Leakages




Activities During Research Field Trip in January 2021

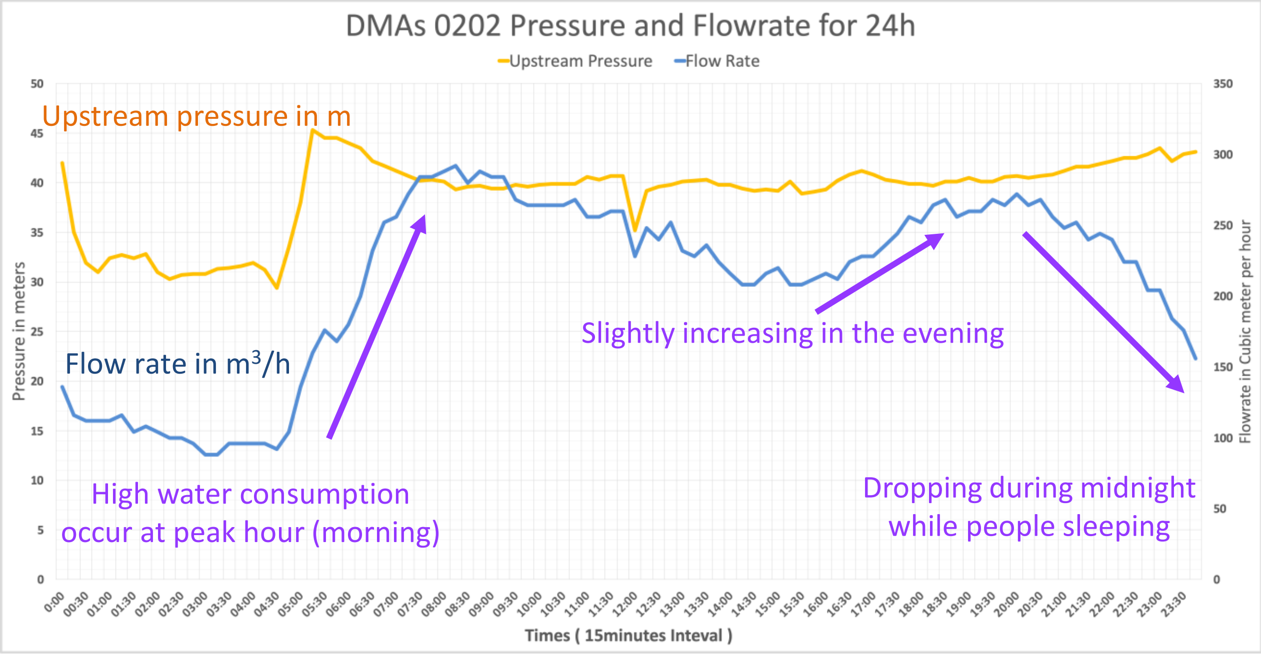
Methodology (Continue) Pressure Management



- Theoretically, leakages(visible and invisible) are in relationship with the pressure. The more pressure at the point of leak, the more water is being loss.
- Therefore, pressure control is use for minimizing water loss in supply area.
- In order control the pressure, Pressure Reducing Valve (PRV) have to be installed at the inlet of the DMA where the only way of flow and pressure supply.

Methodology (Continue)

Flowrate and Pressure Data



Flowrate and Pressure data for 24 hours in DMA 0202

- DMA code 0202 is chosen to be the pilot zone for pressure management.
- It had high NRW ratio, more connection density by a kilometer pipe length and close to 2nd biggest Water Treatment Plant.
- The figure shown about Pressure and flowrate for 24hour data on 1st Jan 2020.
- Maximum pressure Max= 45.3m, Avg= 38.88m and Min 29.4m
- Flowrate Max= 292m^3/h, 210.29m^3/h, Min 88m^3/h

Methodology (Continue)

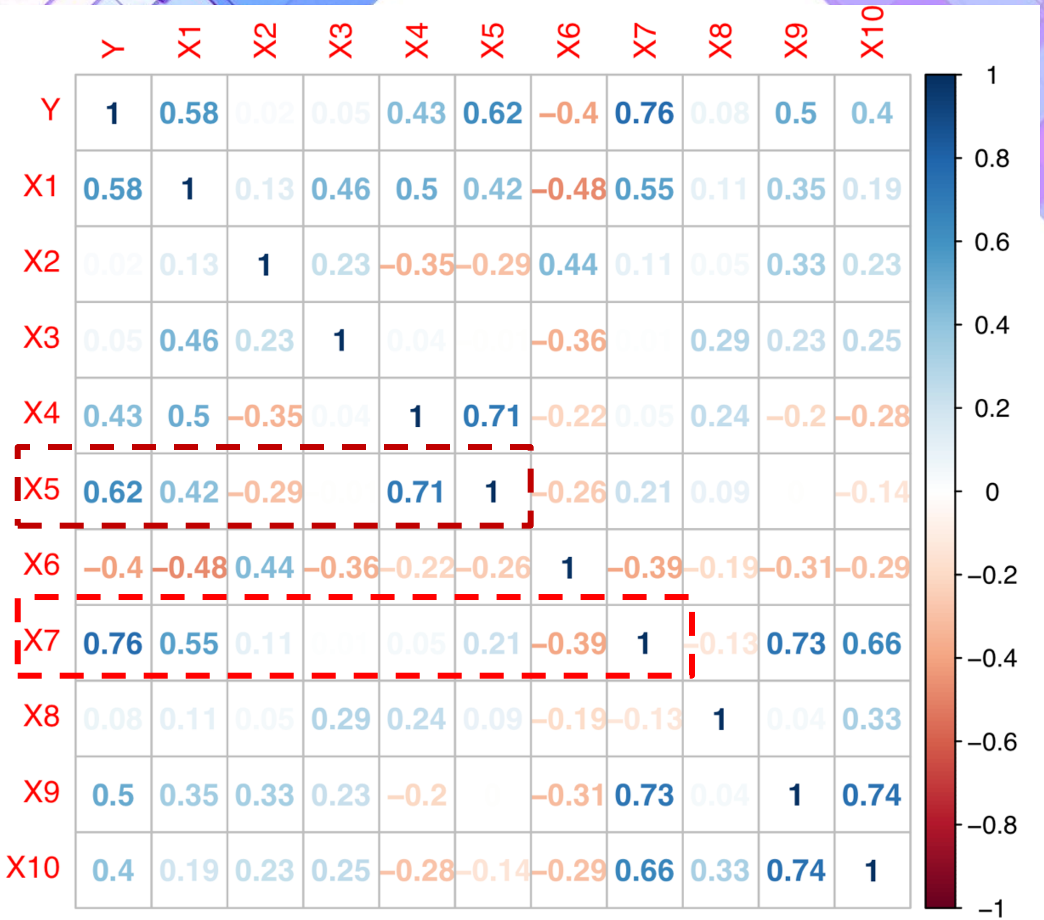
Flow-modulated Pressure Control

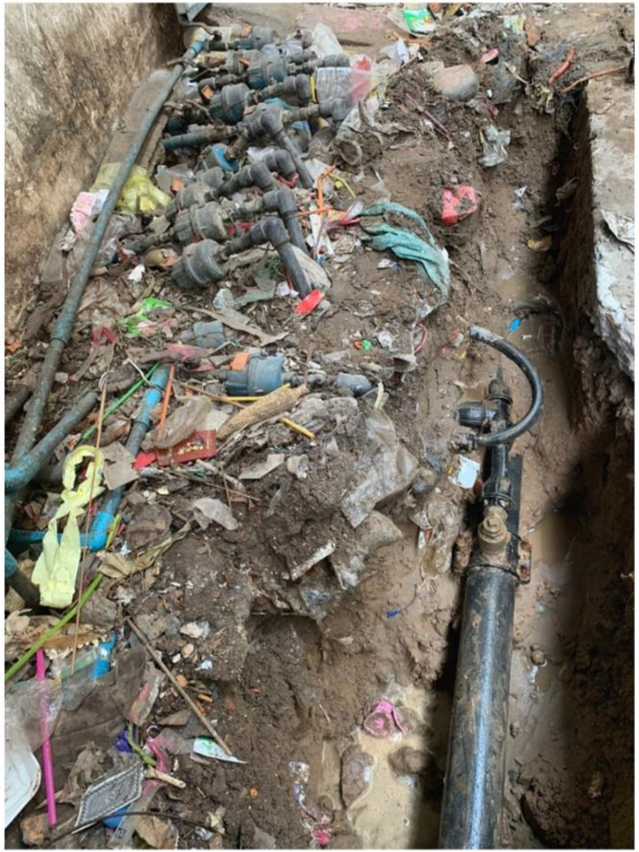
Nº	Type Everyday	Time (GMT+7)	Down Stream Pressure(m)	Critical Point Pressure(m)
1	Everyday	00:00	25.0	10.0
2	Everyday	05:15	30.0	20.0
3	Everyday	06:30	35.0	20.0
4	Everyday	07:15	39.0	20.0
5	Everyday	11:45	30.0	20.0
6	Everyday	16:30	35.0	20.0
7	Everyday	22:15	30.0	20.0
8	Everyday	23:15	25.0	10.0

- The table shown the regulated (set) **downstream pressure and critical point pressure** for 24hours base on flowrate.
- Pressure drop during **Peak hour(Morning and evening)** when people open water tap at the same time.
- During peak hour, pressure **must push to the maximum** to reach the demand from consumers.
- Critical point pressure mush have minimum around **1bar to 1.5 bar** to secure the pressure at the end of DMA.

Regression Result

- Figure show about regression result identify by color and level.
- **Dark blue** mean significant correlation while **Dark Red** was the negative relationship with NRW ratio(Y).
- As the result, Connection Density (X7) had the significant correlation with Y
- The second high correlation was going to be Average Age of Water Meter (X5)

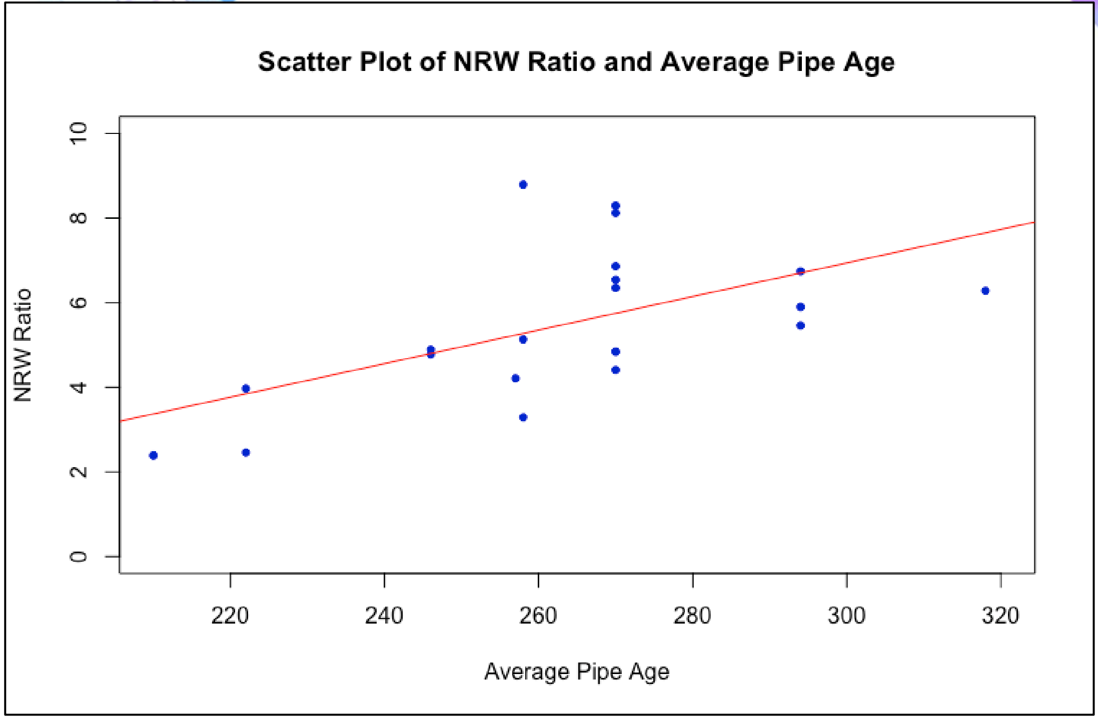




meter inaccuracy which
push the water lost upward.

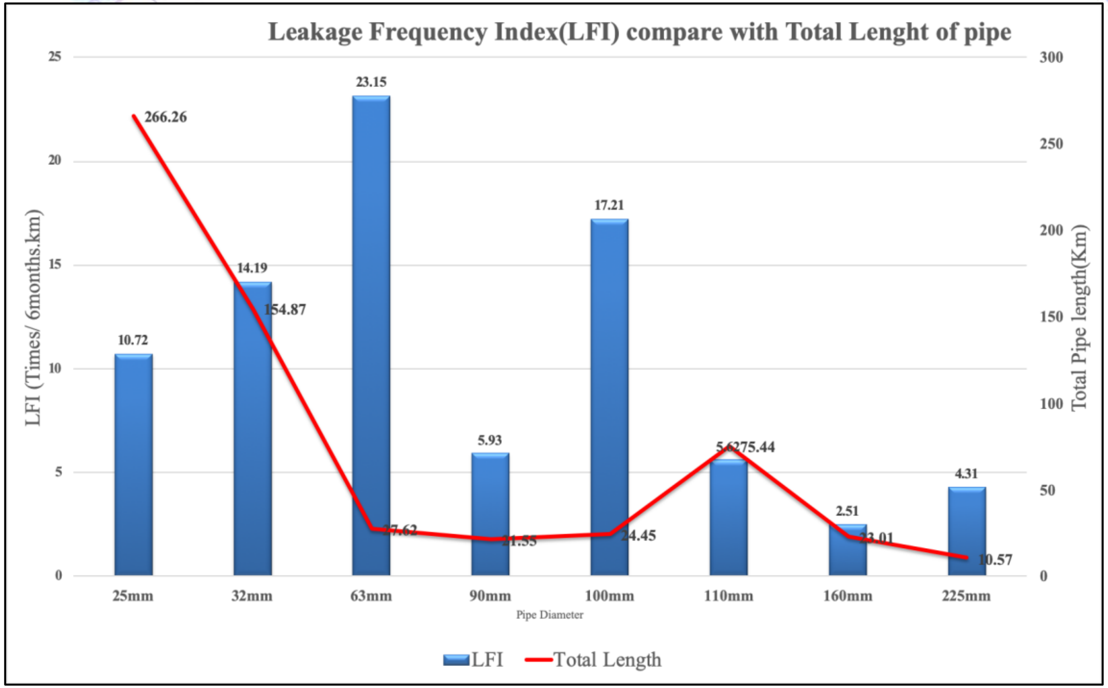
Regression Result

- The third significant correlation on NRW ratio was on average pipe age(X1).
- Deteriorated pipe could cause leakages easily, and physical loss will increase.
- Too many leakages could occurred on the same pipe line when pipe over aged.
- This factor has been the sensitive issue for water utilities including Japan.



Leakages Frequency Index in Study Area

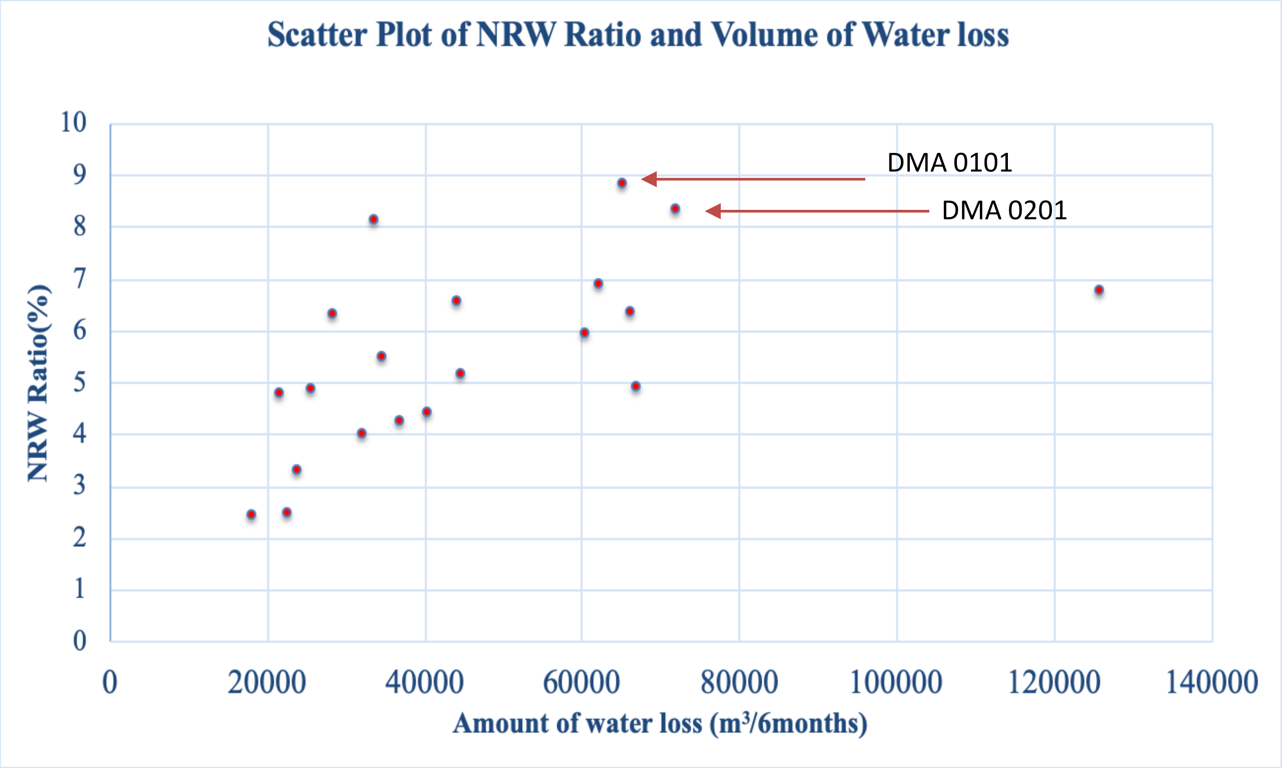
- The Figure shown about LFI in the study are by pipe diameter.
- The data was by diameter of 25mm to 225mm base on leakages frequency occurred during 06 months of study period.
- The result shown diameter of 63mm had most LFI with around 23 times/km in 6 month.
- Base on the result, specific pipe replacement can be set as priority in the future.



Priority Countermeasure for NRW reduction

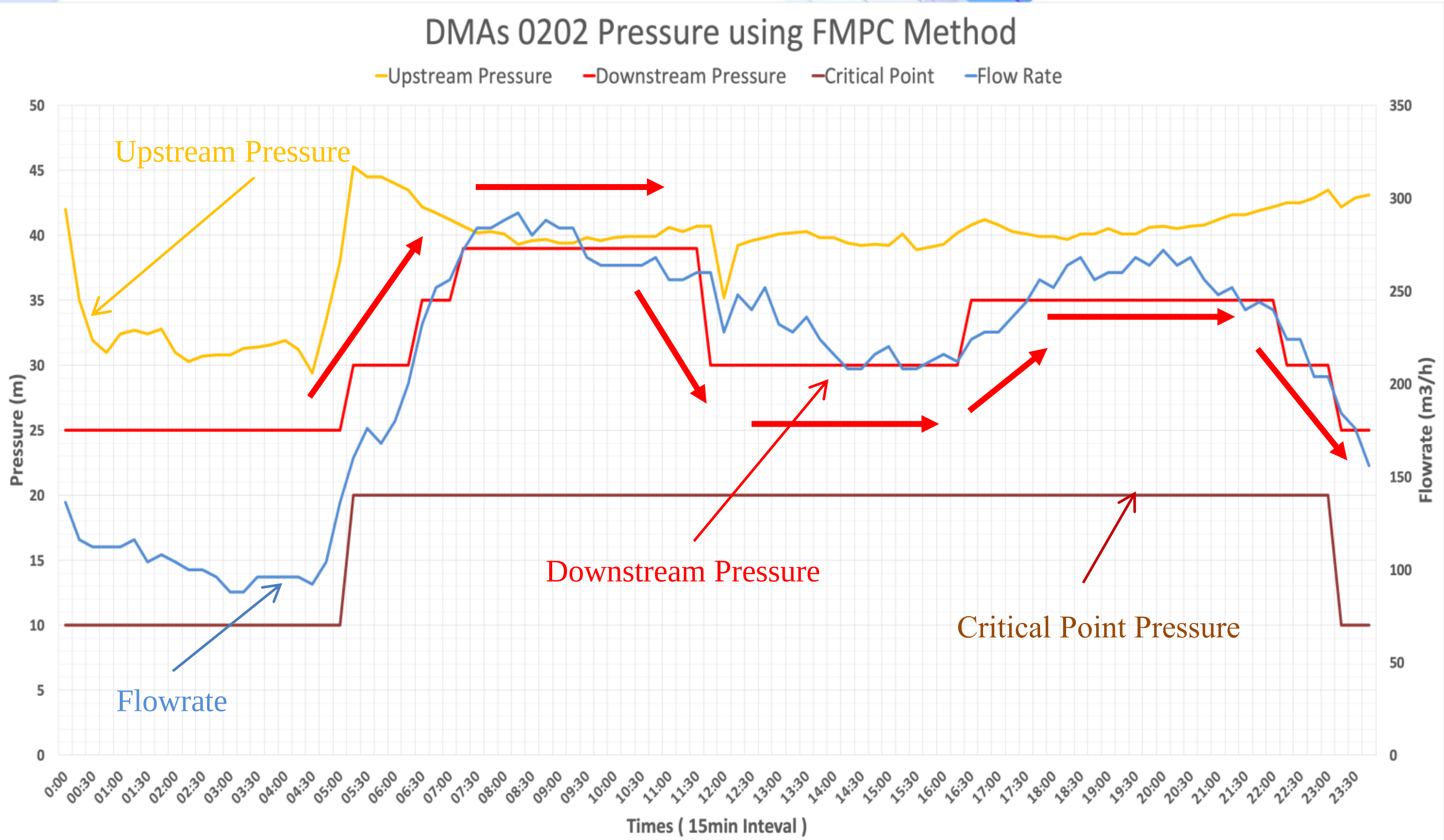
Over Aged Pipe Replacement

- The second high correlation on NRW ratio found in average pipe age(X1).
- Deteriorated pipe could cause leakages easily, and physical loss will increase.
- Too many leakages could occurred on the same pipe line when pipe over aged.
- This factor has been the sensitive issue for water utilities including Japan.



Flow-modulated Pressure Control

Result on Pressure Management



- The graph show about the regulated pressure supply using FMPC method.
- In the morning which is the peak hour, consumption rate will be the highest and pressure will be push to maximum respectfully.
- This Pressure have to adjust base on the flowrate(see the graphic).
- When adjusting the pressure, operator have to make sure that critical point supply with enough pressure supply.

Conclusion

- ✯ The most effected factor for the study was the Connection Density in a kilometer pipe length.

- ✯ The second significant correlation variable found on average age of water meter.

- ✯ The Leakages Frequency Index (LFI) found the highest on pipe diameter of 63mm.

- ✯ Detecting and repairing the leakages could not eliminated when discussing about NRW reduction.

- ✯ Flow-modulated Pressure Control could indirectly reduce water loss invisible leakages and prolong the water facilities useful life

Recommendation

- Water meters for replacement must be high quality with high accuracy.
- Repairing the leakages should be done in short period of time as much as possible to prevent more water lost, also proper instruction must be followed.
- Next focus, PPWSA should find the differences of water input to the DMA before and after applied PRV with same period of time in order to discover quantity of water save by FMPC method.

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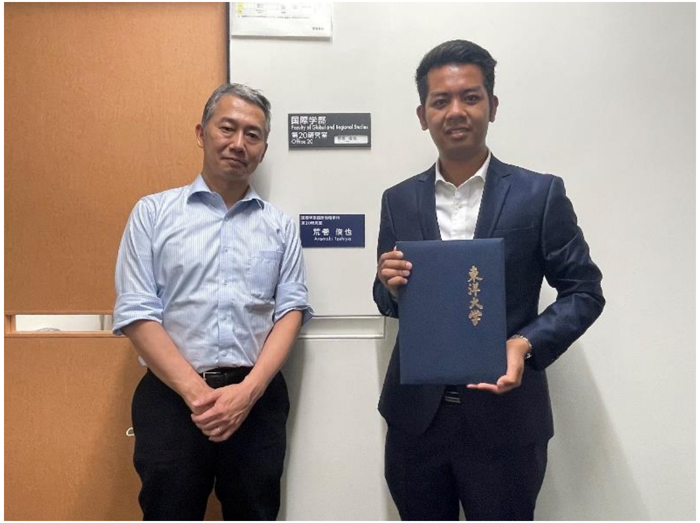
Life in Japan

- To me, education system in Japan is the best one which I have never been experienced.
- Professors offer the course with countless experience with academic, JICA , NGOs or government institutions.
- University provides everything such as journals in the famous database with free access, study room, printers, high-speed internet, mentor, and student support office which we can ask for help anytime.
- My university(Toyo University) was the place not only giving me the degree but with full of my Japan's memory in 2 years.



Life in Japan

- As one of the JDS fellow in Tokyo, there were many thing to do beside research at University.
- For example, Tokyo had around 12 Fellows(Juniors and Senior) which JICE assign to live near to each other.
- Because of this, we were easily gather together on weekend or holiday to discuss everything(daily life) including research difficulties.
- Sometimes, research is quite stress, therefore; doing some favorite activity like shopping, sports, enjoy Japanese scenery or food could help and more productive.
- Japan to me is Endless Discovery

ありがとうございました

Thank you for your attention