TECHNICAL PERFORMANCE INDICATORS FOR SMALL-SIZED WATER SUPPLY NETWORKS – CASE STUDY IN DONG VAN CITY, VIETNAM

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Abstract

Water is the basis of life and livelihoods, and is key to sustainable development. The United Nations General Assembly recognized the human right to water and sanitation and acknowledged that clean drinking water and sanitation are essential to the realisation of all human rights. However, it is a fact that 663 million people around the world still use unimproved drinking water sources such as unprotected wells and surface water, almost all of them belonging to developing world such as Asia or Africa. Paradoxically, these countries also have the highest rate of water waste in the world. Namely, the World Bank estimated that around 30% of water distributed in water supply system equivalent to 45 million m^3 of water is lost daily through leakages in pipeline networks that is enough to serve about 200 million people, and nearly 30 million m^3 of water is delivered every day to customers but not invoiced due to apparent loss (e.g. inaccuracy of water meter, or water theft). In Asian countries, Asian Development Bank estimates that volume of non-revenue water is about 29 billion m^3/year equivalent to $9 billion per year. If water volume of physical losses is cut to half the present level, this volume will be enough to supply for 150 million people.

There are many reasons for this problem in developing world, but inefficiency of water supply system (WSS) management is one of main reasons. WSS in these countries often lacks methods and tools for evaluating the performance in operation and management as well as improvement. Many agencies and organizations around the world have developed detailed performance evaluation frameworks from several indicators to comprehensively cover all the aspects of WSS. However, these systems seem to be only suitable with WSS in developed countries because many factors related to water supply conditions in developing countries have been not mentioned.

For example, in developing world, WSS due to limitation of available conditions (e.g. water scarcity and/or infrastructure constraints) often supplies water some hours per day to customers contingent on available sources and customers' demand, which leads to the presence of private tanks and float valves inside customers' houses to storage water during the period without supplying water of services. The non-continuous operation also causes many unwanted consequences such as decrease of water quality and harmful effects on facilities. Besides, the presence of private tanks (maybe with float valves) not only changes hydraulics' behavior in water distribution system, but also influence negatively on water quality

and inaccurate operation of customer meters. Nevertheless, almost of all available evaluation systems have been not mentioned these relationships and interactions in their systems.

Vietnam is a typical example of developing countries about poor management of WSS. Although Vietnam is a country of sufficient water with total average yearly water nearly 9560m^3 per capita, it still suffers economic water scarcity. According to national aim of Vietnam government, 100% urban population will be provided fresh water from central water supply system in the year 2025 while the coverage of water supply service in 2009 was 73%, especially in small cities (population from 4000 to under 50000) only reached more 50%. According to decree number 42/2009/NĐ-CP of Vietnamese government, the number of small cities accounts for 633 in total 805 cities of Vietnam (about 80%). Hence, increasing the efficiency in operation and improvement of WSS in small cities will be one of key factors to guarantee the sustainable development of water supply sector, especially in limitation or scarce water supply resources.

Small-sized WSS (S-WSS), apart from above-mentioned challenges, suffers much more difficulties than medium and big-sized ones such as low capital and operation costs, poor physical asset, lack of control and measurement devices, missing data. This triggers a lot of difficulties for management and operation of S-WSS. Many specific researches mentioned the problems of discontinuous supply. However, there have not been any researches dealing with this problems for S-WSS comprehensively.

With respect to the management of S-WSS in developing countries, this study will develop a key performance evaluation system and corresponding benchmarks for management and operation of S-WSS in developing countries. Furthermore, the study also proposes suitable methods to collect data in constrain conditions of S-WSS. The study will be executed using the Dong Van city, Vietnam as a case study.

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Table of Contents

List of Figures

List of tables

Abbreviation

ADB	Asian Development Bank
AIG	Average Inaccuracy of Each Group
AWWA	American Water Works Association
BC	Boundary Conditions
BOM	Bureau of Meteorology
CARL	Current Annual Real Losses
CERWASS	Center of Water Supply in Dong Van city
CSA	Canadian Standards Association
CWS	Continuous Water Supply
EC	Electrical Conductivity
GPS	Global Positioning System
HDPE	High-density Polyethylene
HPC	Heterotrophic Plate Count
IBNET	International Benchmarking Network for Water and Sanitation Utilities
IC	Impact of System Performance on Individual Customers
ILI	Infrastructure Leakage Index
IWA	International Water Association
IWS	Intermittent Water Supply
KaWaTech	Vietnamese-German Cooperation for the Development of Sustainable Karst Water Technologies
NRC	National Research Council of Canada
NRW	Non-Revenue Water
NWC	National Water Commission, Australia

NWI	National Water Initiative
OFWAT	Office of the Water Services
PES	Performance Evaluation System
PAT	Pumps as Turbines
PIs	Performance Indicator System
PS	Performance of Total System
PWG	Percentage of Meter Group
SIV	System Input Volume
S-IWS	Small-sized Intermittent Supply System
SM-WSS	Small and Medium-sized Water Supply System
TDS	Total dissolved solids
TPEs	Technical Performance Evaluation System
TIRL	Technical Indicator Real Losses
TPIs	Technical Performance Indicator System
UARL	Unavoidable Annual Real Losses
UFW	Unaccounted-For-Water
UNICEF	United Nations Children's Fund
USEPA	United States Environmental Protection Agency
VNAWS	Vietnam Association of Water Supply
WB	World Bank
WD	Water Demand
WDN	Water Distribution Network
WDS	Water Distribution System
WDN-M	Water Distribution Network and Mountain
WDN-R	Water Distribution Network and Rainfall
WDN-W	Water Distribution Network and Drilled Well
WHO	World Health Organization
WPN	Water Pipeline Network
WSAA	Water Services Association of Australia
WSS	Water Supply System

1 Introduction

1.1 Background

1.1.1 Water scarcity for drinking water in the world

The data from WHO and UNICEF in 2015 estimated that about 663 million people around the world have not accessed improved drinking water sources including water sources from unprotected wells, springs and surface water, almost all of them belonging to developing world such as Asia or Africa (WHO and UNICEF, 2015). Namely, as many as 319 million people in Africa, 134 million people in Southern Asia, 65 million people in Eastern Asia, 61 million people in South-Eastern Asia, and 84 million people in other regions do not have adequate water supplies.

Inefficiency of WSS management is one of main reasons lead to water scarcity in developing countries. Based on data covering more than 900 utilities in 44 developing countries, the World Bank estimated that around 30% of water distributed in WSS equivalent to 45 million m^3 of water is lost daily through leakages in water distribution systems of the developing countries that is enough to serve about 200 million people. Furthermore, nearly 30 million m^3 of water is delivered every day to customers but not invoiced due to apparent losses (e.g. inaccuracy of customer meters, or water theft) (Kingdom, et al., 2006). In Asian countries, ADB estimates that volume of non-revenue water is about 29 billion m^3/year equivalent to $9 billion per year. If water volume of physical losses is cut to half the present level, this volume is enough to supply for 150 million people (Frauendorfer, et al., 2010). Developing countries often face high speed of urbanization, followed by growing water demand. As a consequence, new water resources are developed, and WDN also has to be extended to meet growing demand. The extension of WSS without a good management and operation plan will only lead to a cycle of waste and inefficiency.

1.1.2 Tools for management and operation of S-IWS in developing countries

Agencies and organizations in the world have developed many performance evaluation systems (PES) – a toolkit for evaluating efficiency of WSS, which includes performance indicators (PIs) to measure efficiency of all aspects of WSS. The current PES provide the huge number of PIs covering most possible aspects of WSS from water resources, physical asset, operation, quality of service to environment (Alegre, et al., 2017). Each system has been proposed for a specific objective. For example, PIs of Asian Development Bank (ADB) is created to evaluate the performance of projects implemented by ADB fund, or IBNET of World Bank includes general PIs to give comparative information, simple to use for all WSS around the world but many detail PIs not yet included.

Intermittent water supply system (IWS), in which the pipe network or parts of it are supplied with water for less than 24 hours per day, are the most prevalent in developing countries by dint of low investments, and simplicity in operation and management (Klingel & Nestmann, 2014). Roughly one-third of the population in Latin America and Africa and more than half in Asia that accounts for at least 309 million people are supplied intermittently by water utilities (Kumpel, et al., 2016). In IWS, however, private tanks with float valves (automatically stop collecting water when the tanks full) are added by customers to store water during the time of supplying water of water service and use for all day (M. De Marchis, 2011). The operation intermittently of WSS, the present of private tanks as well as float valves cause many negative effects on both total performance of water pipeline network (WPN) and individual customers, which were mentioned in many studies conducted by Klingel (2012), Tamari & Ploquet (2012), Fontanazza, et al. (2007) and Dahasahasra (2007) including negative impacts on water quality and pipelines systems, high water wastage and losses, inequitable distribution among water users, low pressure, inconvenience, higher investment of water users (for building private tanks), and etcetera.

In general, almost of all available evaluation systems have been not mentioned these relationships and interactions in IWS. Apart from above-mentioned challenges, small-sized IWS (S-IWS) in developing countries suffers much more difficulties than medium and large ones such as low capital and operation costs, poor physical asset, lack of control and measurement devices, missing data, and so on. This triggers a lot of difficulties for management and operation of S-IWS. Many specific researches also mentioned the problems of discontinuous supply. However, there have not been any researches dealing with this problems for S-WSS comprehensively.

1.1.3 Issue of water supply in Vietnam

Vietnam is the easternmost country on the Indochina Peninsula in Southeast Asia. It is bordered on the north by China and to the west by Laos and Cambodia and to the east by the Eastern Sea. The country's S-shape and size is often compared to a bamboo pole with loads at the end (north and south). In the central part of the country Vietnam is only 40 kilometers across. The total land area of Vietnam is 331,212 square kilometers. It has a long coast of 3,444 kilometers. Its 2 major cities are the capital Hanoi in the north and Ho Chi Minh City (formerly Saigon) in the south. Other major cities are the ancient capital of Hue in central Vietnam, the coastal cities of Da Nang and Hai Phong, and Da Lat in the central highlands. Mountains and hills, which occupy three quarters of Vietnam’s territory, are the main landscape in Vietnam. However, 85% among them are low mountains and hills under 1,000 meters above sea level. There are only 1% of mountains that have the height over 2,000 meters above sea level (Source: http://www.toursinvietnam.com/).

Figure 1.1. Vietnam in the South East Asia (source: www.mapsofworld.com)

The water resource of Vietnam is quite sufficient comprising surface water (the total average yearly about 830 billion m^3), groundwater (estimated total 'groundwater potential' of almost 63,000 million m^3 per year) and rainfall (average annual approximately 1940 mm/year) (Brown, et al., 2008). With its population over 95.6 million (2017) (source: http://worldpopulationreview.com), Vietnam has total average yearly water nearly 9560m^3 per capita. Additionally, total water amount of water supply sector solely accounts for 3 ÷ 5% of total demand of economic sectors in Vietnam (Brown, et al., 2008). It could be concluded that total annual water resource of Vietnam outstrips the demand of water supply sectors.

Paradoxically, in spite of above favorable conditions with available water resource, Vietnam water supply sector has been grappling with difficulties because of many reasons, namely: (1) Water resources are distributed unevenly, not only spatially, but over the year. The dry season often lasts between 7 and 9 months with rainfall only of about 20 - 30% of the annual rainfall whilst the rainy season lasts nearly 3 ÷ 5 months, constitutes about 70% to 80% of the annual rainfall; (2) Water quality: High levels of suspended solids, alluviums and contamination; (3) The lack of advanced technical to exploit and storage water; (4) The limitation and unreasonable allocation of budget.

Even when water system input volume is enough, the inefficiency of distribution leads to deficiency and inequity among water users. Namely, households located near water plants, booster pumping station, transmission mains or/and advantaged situations often consume huge amount of water even over 300 ÷ 400 litter/day/capita while disadvantaged areas such as the end of WDN and/or high locations spend about 30 ÷ 40 litter/day/capita, or only are provided water in the limited period from 2 to 4AM or even could not collect water (Lai, 2007). On the other side, high rate of water loss is another reason which causes water deficiency. The average rate of water losses of water supply sector is around 30% equivalent to 1,317 thousand m^3/day (VNAWS, 2010). This water is enough to provide for nearly 9 million people. It is worth noting that 85% water losses occurring water distribution networks (WDN) where water losses is the most difficult to evaluate and repair. Nevertheless, the investment, improvement and rehabilitation of pipeline network seem to be ignored in comprehensive image of water supply system. The evidence is that only 10 ÷ 15% fund of water supply projects to renovate and rehabilitate water supply systems belongs to pipeline network (Lai, 2007).

In the other aspect, according decree number 42/2009/NĐ-CP of Vietnamese government, there are six kinds of cities in Vietnam including two special cities (Hanoi and Ho Chi Minh city) and other cities categorized from 1 to 5 by population size, but small city with population from 4,000 to under 50,000 is mostly common. Namely, the number of small cities occupies 633 in total 805 cities of Vietnam (about 80%). Water supply system in small city always suffers a series of difficulties from limited investment, inadequate infrastructure asset, untrained personnel, bad water quality, and intermittent supply to scarcity of stable water supply sources. According to national aim of Vietnam government, 100% urban population will be provided fresh water from central water supply system in the year 2025 while the coverage of water supply service in 2009 was 73%, especially in small cities where the coverage only reached about 50% of urban population themselves.

Consequently, increasing efficiency in operation and improvement of WSS in small cities will be one of key factors to guarantee the sustainable development of water supply sector, especially in conditions of limitation or scarcity of water supply resources. In order to do this, research on methodologies to evaluate the performance of water distribution networks is indispensable and the first step.

1.2 Objectives of the study

With respect to the problem analysis described in the characteristics of Vietnam water distribution system the main objective of the proposed study is development of a methodology to evaluate technical performance of small-sized water supply networks for developing countries in general, and for Vietnam in particular. The study will be executed using the Dong Van city as a case study. The objective in summary is to development of concepts, technologies and evaluation measures for centralized water supply networks in Dong Van city. In more detail the research should explore the following:

1. Identify the characteristics and issues of S-IWS to be addressed in a technical performance evaluation system (PES).
2. Develop a new PES including performance indicators and benchmarking system for S-IWS in Vietnam.
3. Develop methods to collect the required data under limited conditions of data and support devices.
4. Evaluate the new PES approach by assessing the performance of WSS in Dong Van city (pilot study) in the framework of KaWaTech project.

1.3 Structure of the thesis

The study is made up by **six main chapters**:

Chapter 1 introduces the subject and provides insight into the problem of water distribution system and highlights the importance of evaluating performance in management and operation as well as improvement of water distribution system in developing countries and Vietnam. The need for the research is also highlighted followed by objectives of the study. Lastly, the summary outline of the thesis is presented.

Chapter 2 will define some specific terms such as water supply system (WSS), intermittent supply system (IWS), and small-sized intermittent supply system (S-IWS) as well as the problems of S-IWS in developing countries. Besides, the chapter also provide a basic picture of Dong Van city and KaWaTech project, and explains the reasons why to choose Dong Van city as case.

Chapter 3 presents the literature review of methodologies to evaluate the technical performance of water distribution system in the world, and simultaneously analyses advantages and disadvantages and applicability for S-IWS in developing countries as well as Vietnam. In addition, this chapter introduces efforts of researchers to deal with challenges of IWS.

Chapter 4 will develop a key PES for evaluating technical performance of S-IWS and corresponding benchmarking. This chapter also presents various methods to collect data variables for calculating PES under limited conditions of data, support devices.

Chapter 5 will apply the key PES proposed in chapter 4 for evaluating typically the performance of water distribution system in Dong Van city as well as carrying out some experiments on site to collect necessary data. This real application will be enable to help modification and adaption of the proposed methodologies in chapter 4 more realistically and applicability.

Chapter 6 will show the main conclusions of the study. Furthermore, some critical issues will be pointed out for next studies.

2 S-IWS in developing countries and case study in Dong Van, Vietnam

2.1 Definition of WSS

A water supply system (WSS) is "a system for the collection, transmission, treatment, storage and distribution of water from source to consumers, for example, homes, commercial establishments, industry, irrigation facilities and public agencies for water—related activities" (United Nations, 1997). Herein, the water will be obtained from water sources through intake constructions (channel or/and pipeline system by pumping or gravity) and flow into treatment plant. The treated water will be stored in storage tanks before flowing into pipeline network by pumping or gravity and then finally be distributed to water users.

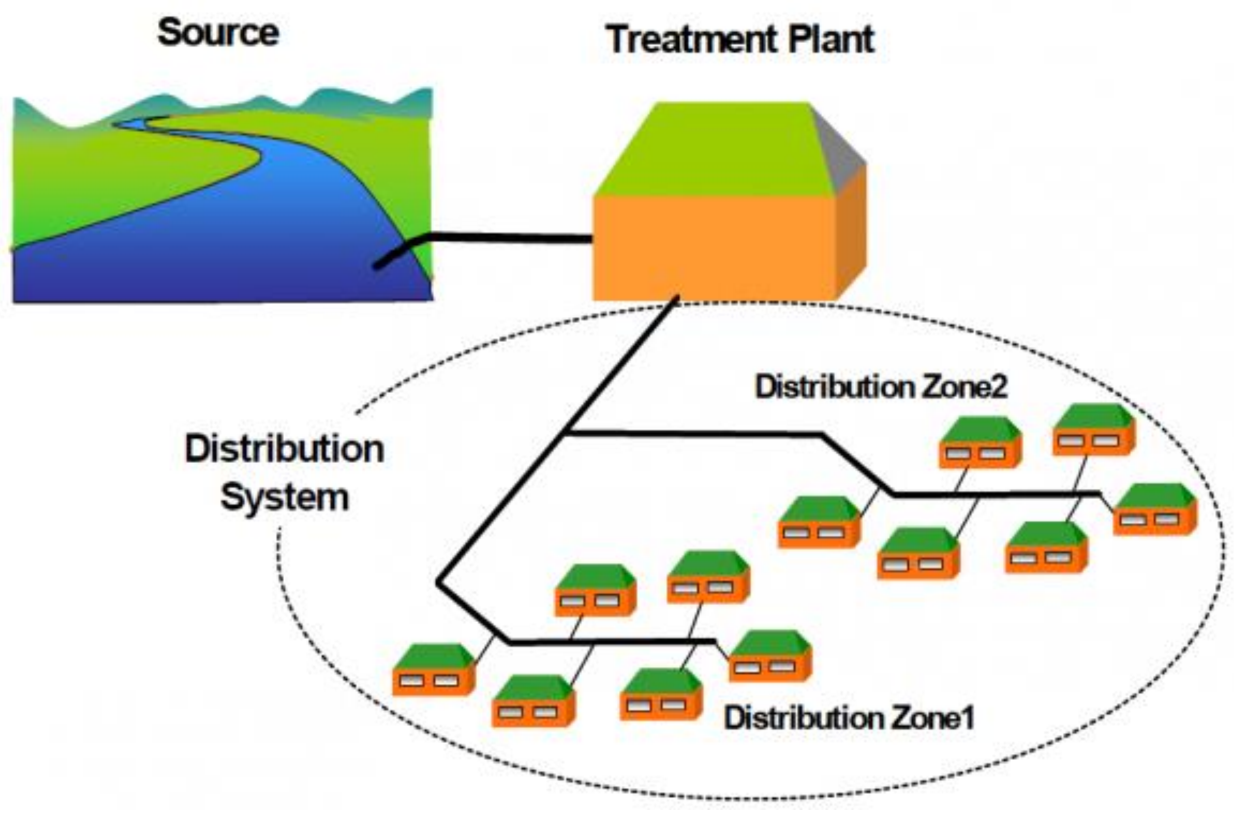


Figure 2.1. The components of the water supply system (source: http://www.ehinz.ac.nz)

The water sources feeding WSS are normally very diverse from surface water (ocean, river, stream, pond, lake, reservoir, and etcetera), underground water (Karst caves and aquifers), and rainfall. Depending on kinds of water sources, sedimentation ponds/tanks could be added to deposit sludge. Distribution system often comprises pipeline system, tanks, reservoirs, valves, hydrants, taps, meters, observation and control devices. Figure 2.1 provides a general image of water supply system.

2.2 Definition of IWS and non-revenue water

Water supply system (WSS) can be operated by two different delivery methods: continuous or intermittent distribution. "The former ensures better management of the water distribution network because the water demand only depends on user requests and the service quality can be better guaranteed" (Freni, et al., 2014), which is mostly common in developed world. In contrast, the intermittent distribution, in which the pipe network or parts of it are supplied with water for less than 24 hours per day is very prevalent in developing countries due to low investment, and easier operation (Klingel & Nestmann, 2014). Roughly one-third of the population in Latin America and Africa and more than half in Asia with piped water supply that accounts for at least 309 million people are supplied intermittently (Kumpel, et al., 2016).

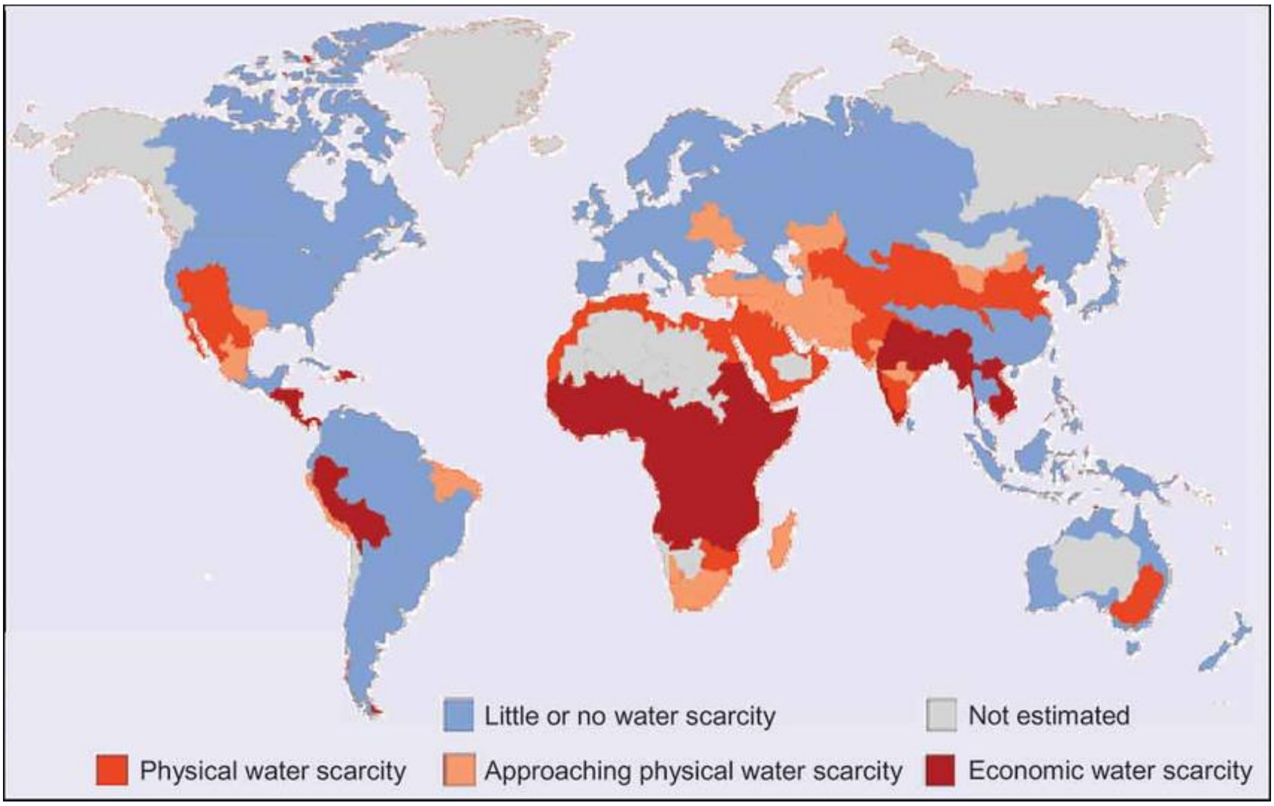


Figure 2.2. Global distribution of physical and economic water scarcity (Parish, et al., 2012)

It is a coincidence that these areas are also known as places of physical/economic water scarcity in the world. For instance, approximately 1.7 billion people (with more than half of theses living in rural areas) in Asian and the Pacific and about 70% of the total population in Africa still did not have access to improved sanitation in 2012 (WHO and UNICEF, 2014b).

Table 2.1. Non-revenue in some developing areas

	NRW (billion m^3/year)	Cost of NRW (billions of US$/year)	Enough water for (million people)	Source
Developing country	27	6	300	WB
Southeast Asia	5	1	22	ADB
Vietnam	0.5	0.1	9	VNAWS

One of reasons lead to water scarcity in such areas is the high amount of non-revenue water (NRW) in WSS. Some data from international organizations estimate that the actual figure for overall NRW levels in the developing countries is probably in the range of 40-50% of the water produced (Fallis, et al., 2011).

2.3 Technical problems in IWS

The operation intermittently with the present of private tanks and float valves causes many negative effects on both total performance of water pipeline network (WPN) and individual customers, which were mentioned in many studies conducted by Klingel (2012), Tamari & Ploquet (2012), Fontanazza, et al., (2007) and Dahasahasra (2007) including negative impacts on water quality and pipelines systems, high water wastage and losses, inequitable distribution among water users, low pressure, inconvenience, higher investment of water users (for building private tanks).

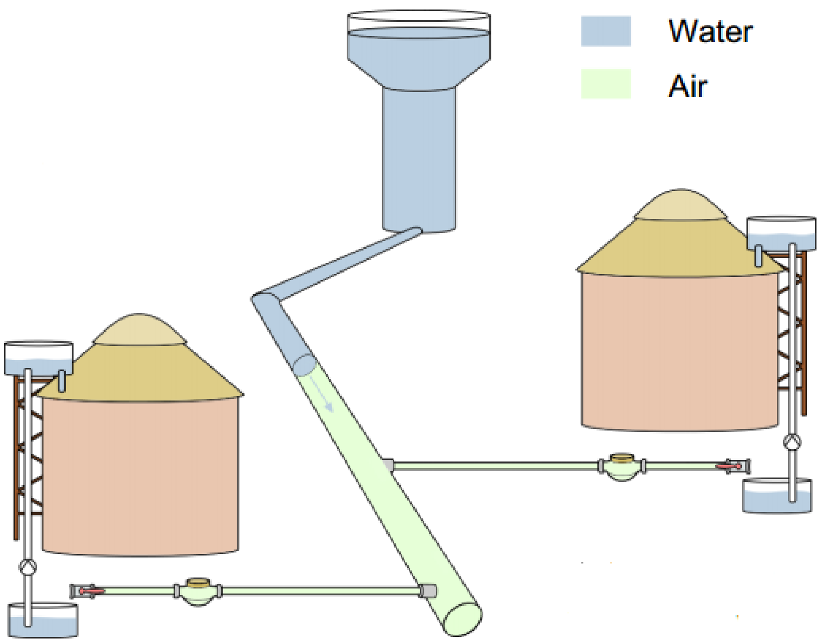


Figure 2.3. Status of IWS during filling process (Walter, 2015)

First, due to operating intermittently, the filling and emptying process will always occur at the beginning and ending of water service period. Namely, the pipeline system will become empty during the time of without supplying water. Then, when water is supplied again, water running through the pipe network and the airflow ahead of the arrival of the water happens always at the beginning of the network filling process. The air flow is distributed through air valves, leakages in pipeline network and service connections, and thus, through water meters of customers (Fontanazza, et al., 2015) & (Van Zyl, 2011). This airflow will be distributed inequality along with pipelines. Normally, high or/and far positions are forced to obtain a huge amount of air volume, particular in connections located at the end of pipeline system. The water meters that have an impeller on the inside measure amount of water through the kinetic energy of the water flow, which could not recognize the difference between water flow and airflow. The water meters, therefore, could not measure exactly the amount of water during the process of the alternating filing and emptying of the pipe network in intermittent water supply (David Walter, 2017). As a result, IWS would cause inaccuracy in metering due to air volume and the air flow will be distributed inequality among customers in distribution.

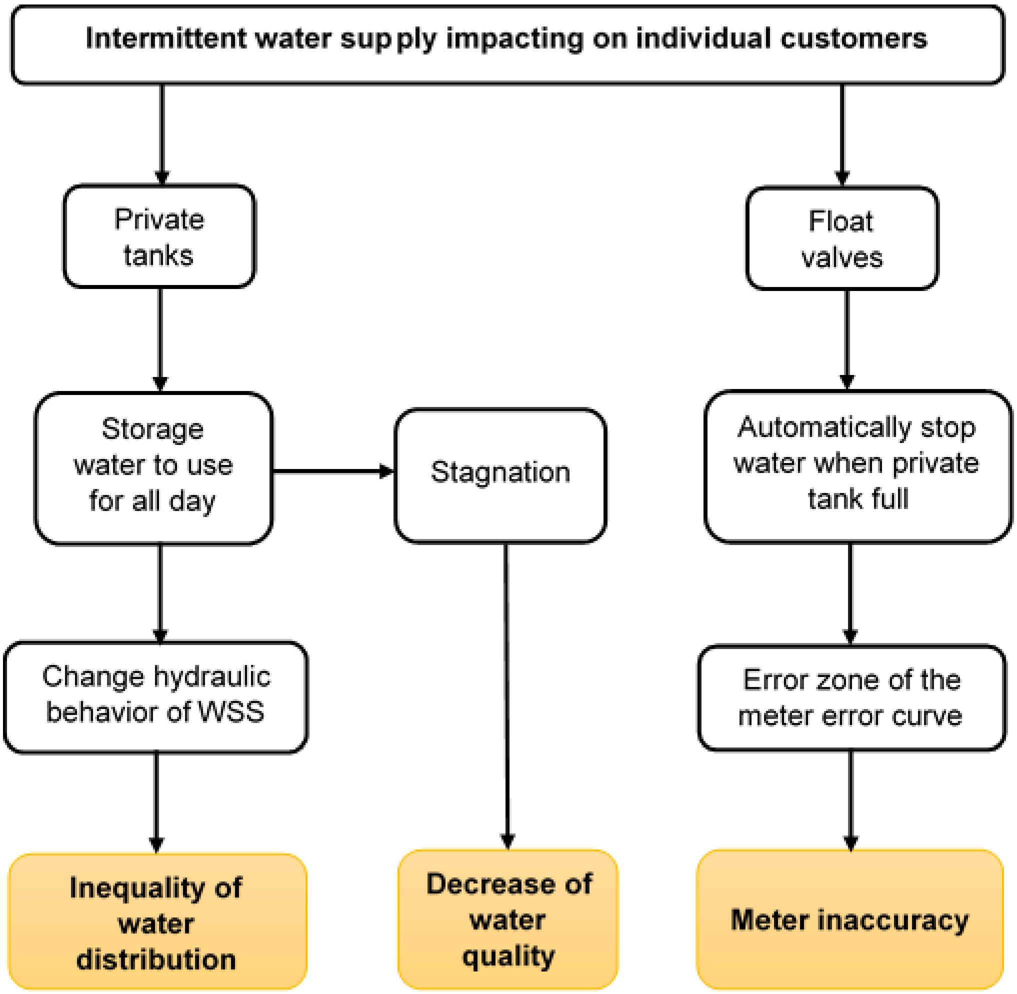


Figure 2.4. IWS impacting on individual customers

Second, this also causes inequity in water distribution among various positions in WSS. Namely, households located in advantaged positions of the network are able to obtain water resource soon after the service period begins whilst others have to wait much longer (M. De Marchis, 2011). If water resources would be insufficient or water supply duration of service not long enough, the disadvantaged ones could completely not collect water from WSS.

Third, the presence of private tanks and intermittent distribution lead to change hydraulic behavior of the pipeline network. The hydraulic behavior in pipeline networks will be depend on the water level of private tanks and the process of filling pipeline networks at the beginning of supplying water.

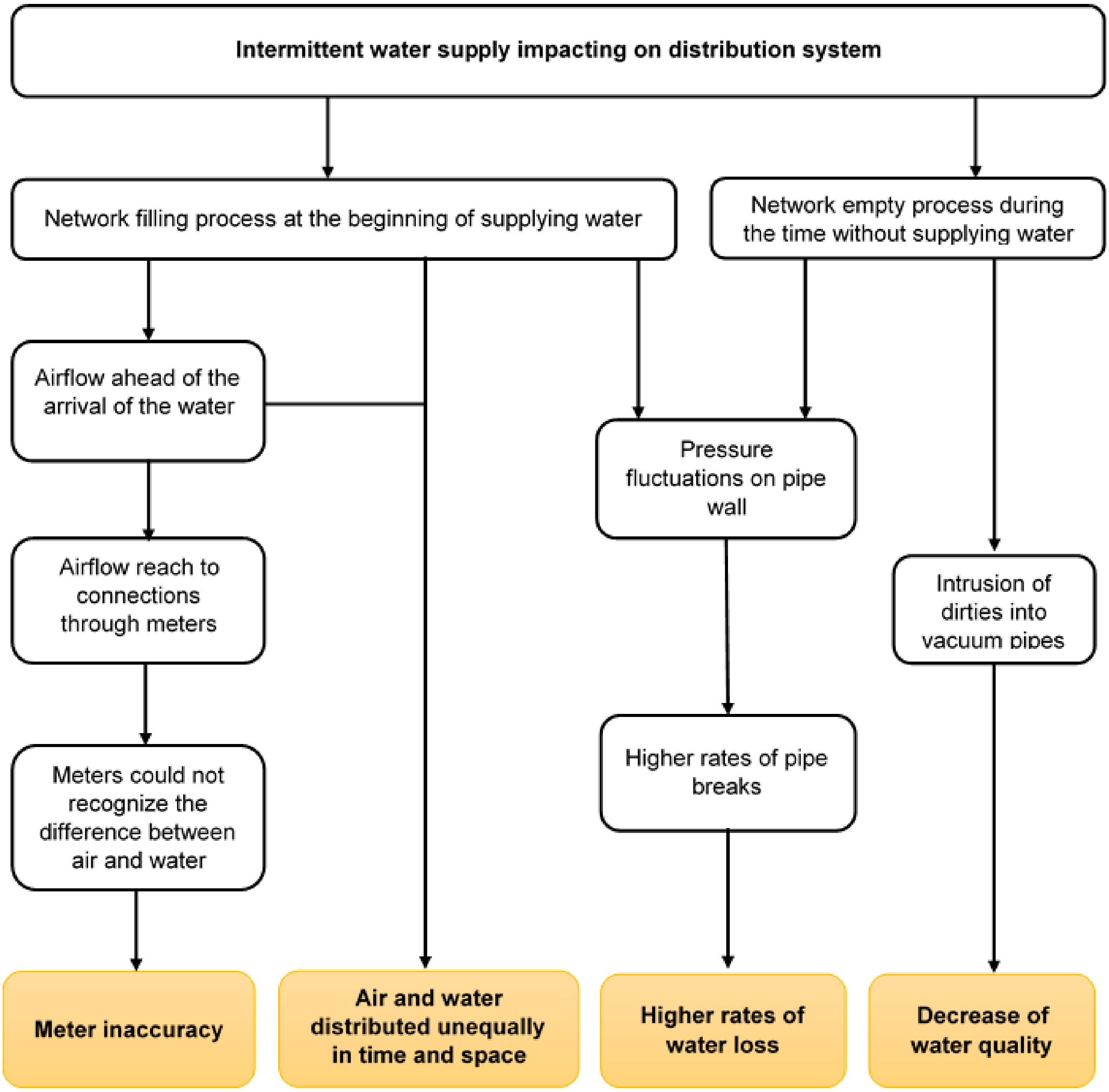


Figure 2.5. IWS impacting on distribution system

Fourth, most pipelines are located underground and near sewage ditch. Thus, contaminated water and soil particles from the surroundings will infiltrate the pipelines through leak openings during the time of without supplying water of service, which leads to extreme decrease of water quality. Besides, the presence of private tanks inside households also have both positive and negative effects on water quality. For instance, roof tanks because of being located at the top of houses often rise water temperature, which can make a better environment for proliferating bacteria. However, roof tanks help to deposit dirt and impurities.

Fifth, private tanks often are installed float valves to stop collecting water automatically when the tanks are full. However, the operation of float valve triggers inaccuracy of water meter. The large impact of private tanks with float valves on meters was explained in details by Criminisi, et al., (2009): “The slow closure of the float valve induces flows that are lower than the starting flow of the revenue meter and are not registered. The larger the surface area of the roof tank or the higher the meter starting flow, the larger the meter under-registration”.

Besides, discontinuous supply also leads to quicker asset deterioration of the water distribution network due to the water hammer induced by the filling process and operation far from design (increasing the rate of burst and leakages), followed by higher real losses (Marchis, et al., 2010).

In brief, comparing with continuous WSS in developed countries, IWS in developing countries has to face some main critical problems in technique as follows:

- Network filling and empty process and the presence of private tanks change hydraulic behavior of WSS, followed by inequality of water and air distribution in time and space.
- Intermittent operation and the presence of float valves inside private tanks result in meter inaccuracy.
- Discontinuous distribution and private tanks impact negatively on water quality.
- WSS operated discontinuously leads to quicker asset deterioration and increase of real loss.

2.4 Definition of S-IWS in Vietnam

The classification of WSS is very diverse around the world depending on specific objectives. The classification can be based on WSS size (e.g. population served, number of connections, the volume of water supplied), the importance and positions of WSS (e.g. special, large central, central, urban, rural), operation condition (e.g. continuous and discontinuous), investment cost, and so on. However, the classification of WSS based on size is the most common.

The identification of small WSS based on size is very different among various organizations. For example, WSS defined is small classification when WSS supplies water for less 3,300 people (USEPA, 2009) or less 125,000 people (WB, 2002), or less 2,500 number of service connections (Lambert, et al., 2010), or less 10,000 number of service connections (McKenzie, et al., 2002). In Vietnam, small city with population from 4000 to 50000 is the most prevalent. Pursuant to decree No. 1210/2016/UBTVQH13 of the Vietnamese Government dated on May 25, 2016 on urban classification, as of April 2017, Vietnam had 805 cities, in which small city accounts for nearly 80%. The WSS for these small cities has many specific characteristics. In this research, water supply system with population served less 50,000 people and operated intermittently is called small-sized intermittent supply system (S-IWS).

Table 2.2. The number of cities according to urban classification of Vietnamese Government (April 2017)

Categorization	The number of cities	Population (P)
Urban special	2 (Hanoi and Ho Chi Minh city)	P ≥ 5 million people
I	17	500,000 ≤ P < 5 million
II	25	200,000 ≤ P < 500,000
III	44	100,000 ≤ P < 200,000
IV	84	50,000 ≤ P < 100,000
V	633	4,000 ≤ P < 50,000
Total	**805**	

(Source: http://vietnambiz.vn/ca-nuoc-co-805-do-thi-tinh-den-thang-42017-21636.html)

Comparing with medium and big-sized WSS, S-IWS frequently grapples with much more difficulties from limited investment, asynchronous infrastructure asset, and untrained personnel to scarcity of stable water supply sources. Basically, there are some kinds of difficulties in S-IWS in the following:

The lack of fund: This is mostly the first reason because the investment effects on almost of all aspects of WSS comprising infrastructure asset, equipment, maintenance scheme, operation and management of water undertakings, quality of services, even water resources input. Obviously, finite capital will impact negatively on all aspects of WSS. The lack of fund for S-WSS derived from some reasons consists of the lack of local governmental fund, the priority of government investment for large-sized WSS or/and strategic positions, misuse of fund and corruption.

Physical asset: The physical asset is frequently inadequate. In these systems, water is often pumped directly into pipeline system without treatment or may be treated, but very basic (e.g. sedimentation pond/tank). Besides, observation and control devices such as instruments to record water input volume of WSS, pressure control valve, air valve are hardly installed in WSS.

The weakness of operation and management: The inefficient operation and management of water utilities are revealed through some sides such as incomplete functional units of management apparatus, untrained personnel. This problem triggers off waste fund and public asset, low quality of repair service, and increase of unauthorized consumption. In addition, limited awareness about precious water resources along with unprofessional working manner of staffs of water utilities also are other reasons lead to the weakness of operation and management.

Water resource input scarcity: S-IWS are often in disadvantaged positions with small resident groups far from central cities such as rural areas, remote regions, high mountains where face physical water scarcity. Karst areas are a typical example. Due to the high infiltration rates of Karst, water usually assembles in underground Karst cave networks forming underground water resource, which are potential resources for the water supply in those Karst areas. But the extreme topography and complexes hydrogeology of Karst areas make it extremely difficult to exploit and distribute those water resources for water supply purposes.

2.5 Case study in Dong Van city, Vietnam

2.5.1 General information

Dong Van city is the Northeast of Dong Van District and shares the border with Thuong Phung, Pai Lung, Ta Lung, Ta Phin, Thai Phin Tung, Lung Tao, Ma Le commune and China. It covers an area of 30.31 km2 with about 5,760 people.

The whole city of Dong Van is located in Karst area of Vietnam where has many specific characteristics about physical features as well as socio-economics. Weather conditions of Karst regions in Vietnam are influenced by the tropical climate. The average annual rainfall is 1600 - 1700 mm/year, but not distributed evenly throughout the year. The dry season lasts eight months, from October to May, with rainfall only of about 15 - 20% of the annual rainfall. The rainy season lasts four months, from end of May to end of September, and constitutes about 80% to 85% of the annual rainfall. Permanent surface flows are concentrated on major rivers, such as Lo, Gam, and Chay River. Temporary surface runoffs generally are formed only after heavy rains. Due to the high infiltration rates of Karst, water usually assembles in underground Karst cave networks forming underground water resource, which are potential resources for the water supply in those Karst areas. But the extreme topography and complexes hydrogeology of Karst areas make it extremely difficult to exploit and distribute those water resources for water supply purposes.

Figure 2.6. Landscape of the Karst region in the Ha Giang province (http://dongvangeopark.com) (left) and local people collecting water with great efforts (Nestmann, 2011) (right)

A typical example of a Karst area facing the above mentioned boundary conditions is the Dong Van city, the chosen study area. The main part of the population is ethnic minorities, who tend to live up on the hillsides rather than down in the narrow valleys. According to the described constraints of the Karst, accessible water resources are very scarce and often only accessible with great efforts, especially during dry season.

2.5.2 Water supply system in Dong Van city

Water distribution networks in Dong Van city are fed by To 5 water sources including Lang Nghien pump station, To 5 pump station (pump water from drilled well 1 and 2), Frontier Post pump station, Xom Moi, and Doan Ket. At the moment, Lang Nghien and To 5 pump stations are operating while other sources have stopped functioning because of without water.

Water distribution system in Dong Van is located in a large range of elevation from +1180 to +1220. This system is fed by Lang Nghien pump station that pumps water daily from 7:00 to 20:00 in rainy season, but in dry season supply time of service is contingent on available water at storage tank due to water scarcity. Generally, the coverage of water supply service in Dong Van city is quite low. The number of households using 100% water from WPN is merely 45.2% whereas 39.2% households use water from other sources such as drilled wells, rainfall, and from high mountains.

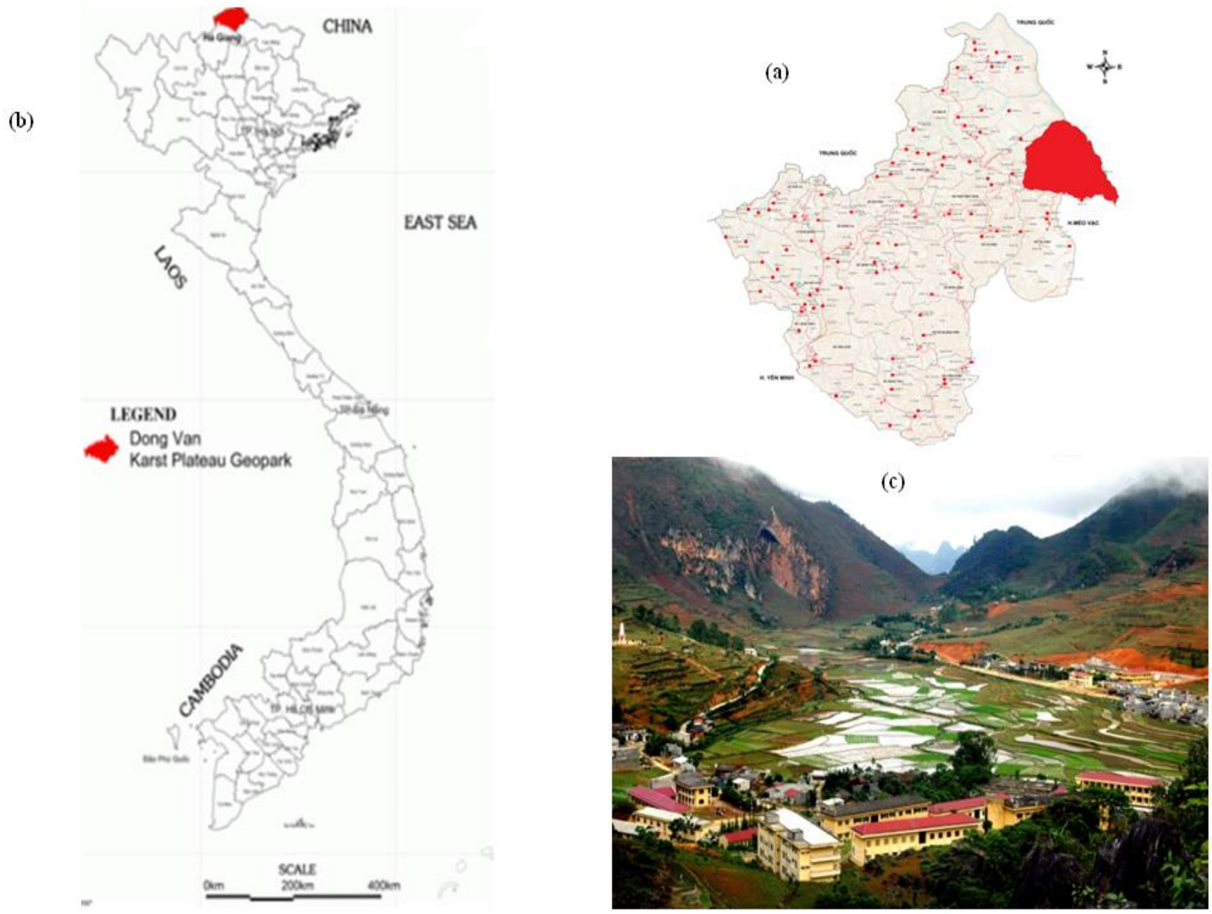


Figure 2.7. Situation of Dong Van city in Dong Van district (a), Dong Van district in Vietnam (b) and the picture of Dong Van city (c) (http://dongvangeopark.com)

According to categorization scheme of Vietnam cities, Dong Van city belongs to the group of small city that accounts for 633 in total 805 cities of Vietnam (approximately 80%). Dong Van is one of strategic cities of Ha Giang province because of its location, geography, topography, socio-economic characteristics. The choice of Dong Van city as case study because of the following reasons:

- WSS in Dong Van city belongs to the group of small-sized water supply system which accounts for nearly 80% in 805 cities of Vietnam.
- Having represented attribution for small-sized water supply system including: (1) The low coverage of water supply service approximately 50%; (2) The asynchrony and deterioration of asset infrastructure such as lost pipelines or/and damaged public tanks; (3) The lack of a scientific basis in calculation, design and construction of water supply systems.
- Characteristics of WSS such as high water losses, inequitable distribution, intermittent operation, management, and so on can represent for the huge amount of small-sized water supply system group in Vietnam.
- WSS in Dong Van city often faces scarcity of input water resources during dry season. Therefore, solutions which improve WDN in Dong Van city and look for a suitable water development strategy can be applied for a series of cities in physical water scarcity condition.
- This system is independent WDN; thus, it is convenient for study process and new technical applications.

Equally important, Dong Van city is one of implemented areas of KaWaTech project; thus, the study can inherit database, experiences and utilize some equipment from KaWaTech project.

2.5.3 Dong Van WSS in KaWaTech project

The main objective of the project - Vietnamese-German Cooperation for the Development of Sustainable Karst Water Technologies (KaWaTech) is to use existing hydro power potential in order to pump water for water supply. KaWaTech implement innovative pumping and distinct technology to pump water from Seo Ho River to Ma U tank with nearly 600 meter high, after that water from Ma U tank will be distributed to Dong Van city and remote areas around Dong Van city by gravity. (See Figure 2.8).

For specific, the water would be pumped from Seo Ho hydro power plant to a storage tank Ma U (1 module 950.000; 2 modules 1.725.000l/d) by dint of the support of PAT-Pump. Subsequently, such water will be distributed to living areas including Dong van city (1 module 650.000; 2 modules 1.410.000l/d) by gravity (Nestmann et al., 2014).

The preliminary estimate of demand of living water of Dong Van city: 6000 people x 90 litter/day/person = 540.000 l/d. Comparing between possible water supply and water demand realizes that the water supply meet the demand of living water at present and in the future if we optimize the distribution of water supply networks and saving water in use of citizens.

When water from KaWaTech project join in the existing network, many questions need to be answered in the following:

- Define options of connecting existing WSS with new water source such as position and method of connection.
- Options of operation and management with water source: According to operation plan of the KaWaTech, WSS in Dong Van city will be transferred from IWS into CWS with operation pressure from 2 to 4bar. The question is whether the existing network can operate with these pressure? Pipe breaks will happen?
- Evaluate the performance of the KaWaTech project: It is necessary for a performance evaluation system of network before and after implementing the project.

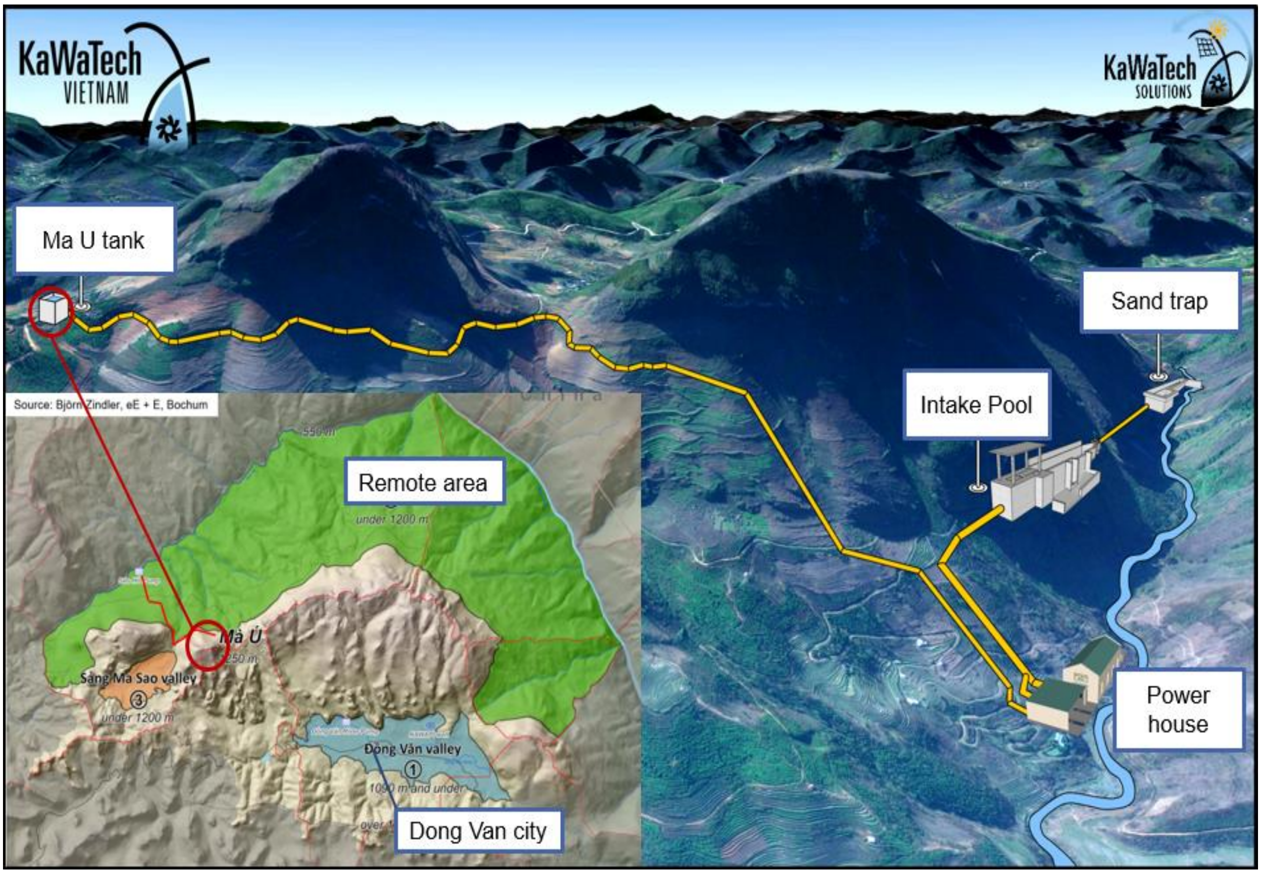


Figure 2.8. Study area of KaWaTech project (Nestmannn, et al., 2014)

2.6 Conclusions

The water supply system operated discontinuously triggers many unwanted technical consequences for both network system and individual customers such as inequality of water and air distribution in time and space, meter inaccuracy, low water quality, quicker asset deterioration, and higher water losses. In Vietnam, small-sized WSS that provides water for between 4000 and 50000 people is the most popular (account for 80% in total). All these systems is operated intermittently (S-IWS). The KaWaTech project using PaT technology pumps water from Seo Ho River to supply water for Dong Van city and surrounding zones. However, looking for the best method to combine this source with existing network as well as evaluating the performance of the KaWaTech are still far from easy.

A technical performance evaluation system is the key and first step to deal with above-mentioned issues. The next chapter will look for methods of evaluating the technical performance of WSS available around the world and suitable to apply for characteristics' S-IWS in Vietnam.

3 Review of methods to evaluate technique performance of S-IWS

3.1 Introduction

Each WSS is operated with specific objectives, but always having the same target is to have maximum possible efficiency with minimum cost. In order to achieve this objective, performance evaluation of WSS is a key step and an indispensable part of all activities related to WSS from operation, maintenance to improvement (Alegre, et al., 2017).

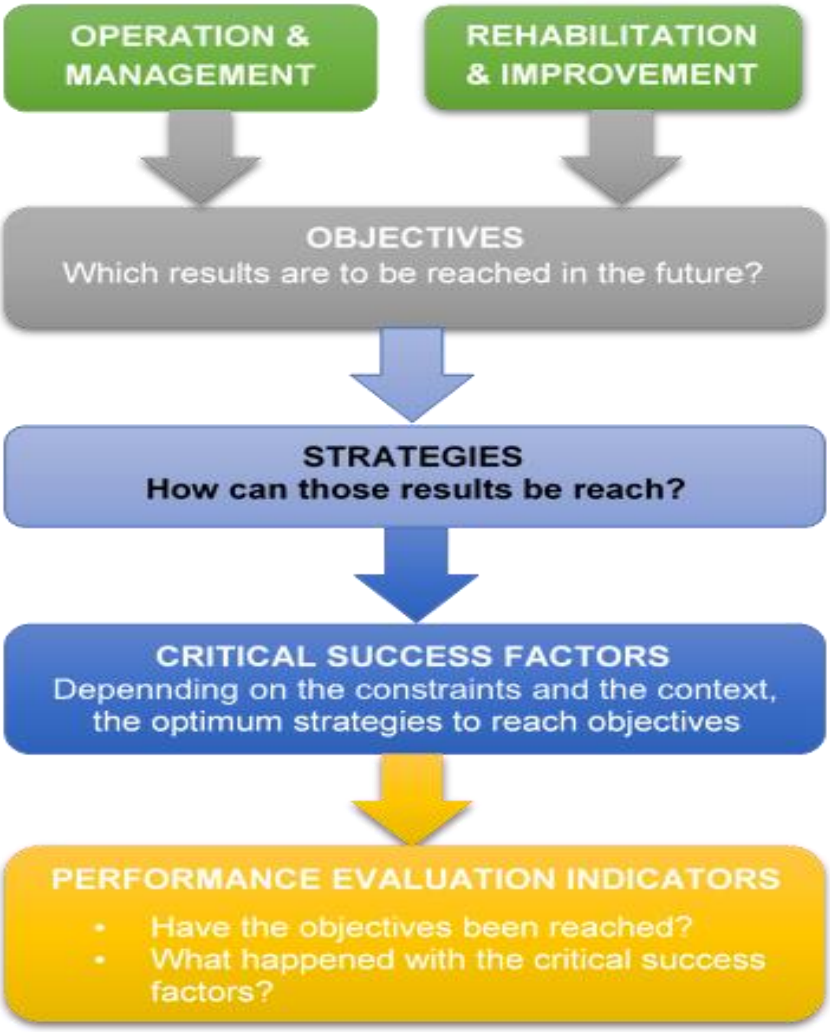


Figure 3.1. PIs as a part of a performance measurement system (based on Alegre, et al., 2017)

In general, PIs system can be broken into three groups comprising technical, personnel/staff and financial/economic indicators in general. Three such groups have a very close interaction and interdependent relationship. For instance, a good strategy of leakage management or an optimal personnel number will increase water undertakings' revenue while financial indicators will dominate all activities of water utilities (see Figure 3.2).

It was the fact that defining PIs and corresponding variables are a complicated and time-consuming progress, which requires recorded data recovering all activities related to WSS. Variables for calculating personnel and financial PIs groups are frequently not difficult to collect from operation data such as pumping diary, customer contracts, financial bills, and etcetera. Inversely, collecting variables of technical performance indicators (TPIs) is really far from easy due to WSS's very particular characteristics. For instance, most pipeline system are located underground that causes extreme challenges of detecting leakages and bursts. To identify these variables, it requires many supports from modern devices (e.g. leak detector), state-of-the-art methodologies, experts, and so on depending on specific conditions.

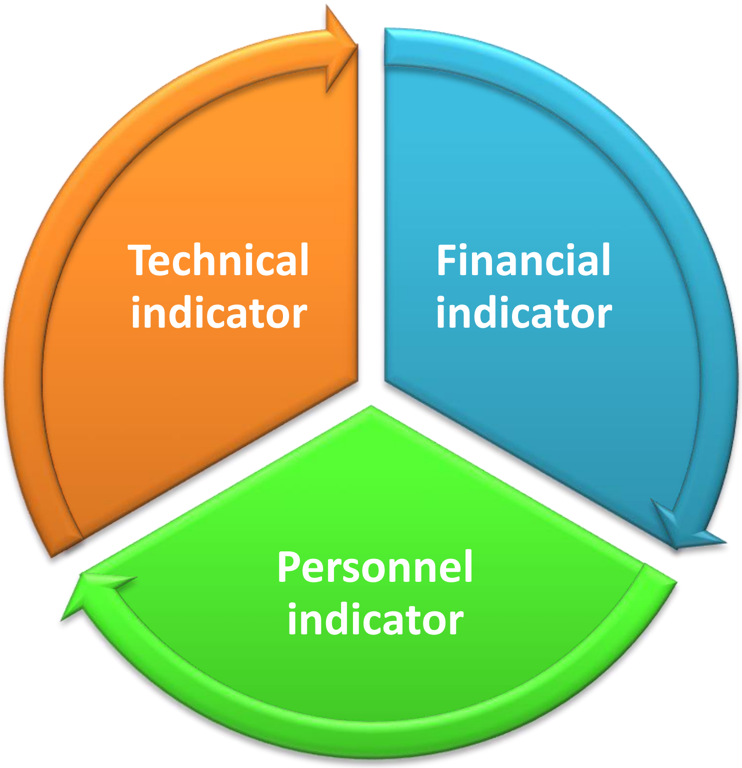


Figure 3.2. Components of PIs system and their relationship

The technical performance evaluation of S-IWS grapples with more extreme difficulties in developing countries in general and in Vietnam in particular due to many reasons.

Missing data for evaluation progress: S-IWS is hardly installed measurement equipment as well as other management and control devices. As a result, many kinds of important data are mostly not available such as system water input volume, water consumption of customers, leakages, failures, water quality, and so on. Even if some data are available, the data are often non-continuous and low reliable because of many reasons (e.g. untrained personnel, without regulations of obligation of informant or no independent organization to assess data management efficiency).

Lack of support devices for collecting and measuring data leakage detector, equipment of measuring water pressure, discharge and so on….

Limitation of applying state-of-the-art methods for evaluation process due to particular characteristics of S-IWS. For example, most current hydraulic stimulate modules for pipeline system such as EPANET are applied for continuous water supply system. Nevertheless, S-IWS often supply water some hours per day and pipeline system is rarely full of water, followed by the presence of private tank with float valve inside customers' houses, which changes hydraulic behavior of water distribution system. Thus, the application of these modules is impossible.

For the reasons above, technical performance evaluation of WSS, especially in S-IWS in developing countries is one of the most difficult steps and plays an important role in all activities related to WSS from operation, maintenance to improvement. With respect to the issues analysed, this chapter will include main contents in the following:

- Overview of current technical performance indicators (TPIs) of WSS through the world and application of these systems for evaluating technical performance of WSS in developing countries.
- Overview of methods to collecting variables for evaluation progress.
- Analyse advantages and disadvantages of these systems as well as pros and cons of methods to obtain corresponding variables for calculating TPIs in application them for S-IWS in developing countries.
- Present further contents of the study

3.2 Review of available technique performance evaluation system

There are some available performance evaluation system in the world such as IBNET of World Bank, PIS of International Water Association (IWA), PIS of Asian Development Bank (ADB), and so on. The number of indicators on the existing indicators probably reached hundreds of indicators until now.

3.2.1 PIs system of International Water Association (IWA)

This system was published the first time with 133 indicators in 2000, and then, revised and complemented some new PIs in the second and third edition in 2006 and 2017 with 170 PIs in total including 93 TPIs (Alegre, et al., 2000, 2006, and 2017). These TPIs is broken down into four groups from water resources, physical, operational to quality of service. Each one of these PIs groups is also divided into subgroups to help identify the use and user of a certain indicators or indicators.

Table 3.1. TPIs system were introduced by IWA

No.	Groups/subgroups	TPIs number
1	**Water resources indicators**	**4**
2	**Physical indicators**	**15**
2.1	Treatment	1
2.2	Storage	2
2.3	Pumping	4
2.4	Transmission and distribution	2
2.5	Meter	4
2.6	Automation and control	2
3	**Operational indicators**	**44**
3.1	Inspection and maintenance of physical assets	6
3.2	Instrumentation calibration	5
3.3	Electrical and signal transmission equipment inspection	3
3.4	Vehicle availability	1
3.5	Mains, valves and service connection rehabilitation	4
3.6	Pumps rehabilitation	2
3.7	Operational water losses	7
3.8	Failure	5
3.9	Water metering	4
3.10	Water quality monitoring	5
4	**Quality of service indicators**	**34**
4.1	Service coverage	5
4.2	Public taps and standpipes	4
4.3	Pressure and continuity of supply	8
4.5	Quality of supplied water	5
4.6	Service connection and meter installation and repair	3
4.7	Customer complaints	9
Total		**93**

In general, the IWA PIs system reflects almost of all important technical aspects of water supply system such as efficiency of using water resources, water losses, quality of supplied water and water quality monitoring, pressure and continuity of supply, service coverage. Equally important, author group also introduced the concept of water balance terminology to seek and identify all components of consumption and losses in a standardized format.

Table 3.2. Water balance terminology (Alegre, et al., 2017)

<table>
<tr><td rowspan="9">System input volume</td><td rowspan="4">Authorized consumption</td><td rowspan="2">Billed</td><td>Billed & metered</td><td rowspan="2">Revenue water</td></tr>
<tr><td>Billed & unmetered</td></tr>
<tr><td rowspan="2">Unbilled</td><td>Unbilled & metered</td><td rowspan="7">Non-revenue water (NRW)
Unaccounted-for-water (UFW)</td></tr>
<tr><td>Unbilled & unmetered</td></tr>
<tr><td rowspan="5">Water losses</td><td rowspan="2">Apparent losses</td><td>Unauthorized consumption</td></tr>
<tr><td>Metering inaccuracies</td></tr>
<tr><td rowspan="3">Real losses</td><td>Leakage on mains</td></tr>
<tr><td>Leakage at tanks</td></tr>
<tr><td>Leakage on service connection</td></tr>
</table>

3.2.2 IBNET indicators of World Bank (WB)

WB developed the International Benchmarking Network for Water and Sanitation Utilities (IBNET). "IBNET is used as a toolkit to support access to comparative information that will help to promote best practice among water supply and sanitation providers worldwide and eventually will provide consumers with access to high quality, and affordable water supply and sanitation services" (http://www.ib-net.org). IBNET indicators have 33 TPIs (out of a total of 110) and are set according to 7 categories including: Service coverage, water consumption and production, non-revenue water, meters, network performance, quality of service, assets. Annually, WB use this toolkit to assess the efficiency of water utilities throughout the world both developed and developing countries.

Table 3.3. IBNET TPIs system

No.	Groups/subgroups	TPIs number
1	Service coverage	4
2	Water consumption and production	11
3	Non-revenue water	3
4	Meters	2
5	Network performance	2
6	Quality of service	8
7	Assets	3
Total		**33**

Generally speaking, IBNET includes general PIs to give comparative information, simple to use for all WSS around the world but many detail PIs not yet included. For example, IBNET system assesses the network performance in terms of number of breaks per kilometer per year; in fact, the efficiency of physical asset should be considered amongst all the physical components of the system such as pumping, valves, hydrants, treatment, pipeline network, public tank, and so on.

3.2.3 PIs system of Asian Development Bank (ADB)

In order to conduct result-based management based on specific targets established by ADB, this organization has developed an assessment system with 55 PIs including 15 PIs at impact level and 40 at outcome level for urban water supply (ADB, 2015). PIs in both impact and outcome groups are broken down into subgroups consistent with various targets. The objective of ADB PIs system is to assess performance of projects implemented by ADB fund.

Table 3.4. ADB TPIs system

No.	Groups/subgroups	TPIs number
1	**Impact level**	
1.1	Target 1: Meeting the needs for urban development to ensure water supply for living, production and other construction in urban areas	8
1.2	Target 2: Improving the life quality of residents to reduce the occurrence of water-borne diseases	7
2	**Outcome level**	
2.1	Target 1: Improving water supply capacity through developing and improving water sources and building and rebuilding water plants and water supply pipeline networks	9
2.2	Target 2: Improving the quality of drinking water through improving and protecting water source, building new water treatment facilities and updating pipelines	8
2.3	Target 3: Improving the efficiency in water supply through building and rebuilding water plants and water supply pipelines	7
2.4	Target 4: Improving the efficiency in management and operation of the water supplying organization	7
2.5	Target 5: Improving the water supplying conditions for poverty stricken population in urban areas	4
2.6	Target 6: Promoting the private sector′s participation in the construction and operation of urban water supply	5
	Total	**55**

Nevertheless, such system also introduced new several indicators related to water quality (e.g. water-borne diseases, free chlorine residuals, E. coli, and so on) which can take into consideration to apply for S-IWS in developing world.

3.2.4 PIs system of National Water Commission, Australia (NWC)

National Water Commission collaborates with Water Services Association of Australia (WSAA), National Water Initiative (NWI) Parties, and Bureau of Meteorology (BOM) to publish handbook of national performance framework for performance evaluation of both urban and rural water utilities in Australia (NWC, 2013). The 113 TPIs out of a total of 180 PIs provided in this data handbook are grouped under the following 5 headings: 57 water resources PIs, 13 asset PIs, 19 customers PIs, 17 environment PIs, and 7 public health PIs. Although NWC introduces a huge number of PIs to assess WSS, many critical indicators have not been addressed such as personnel and operational (pump, storage, network inspection, leakage inspection, etc.) indicators.

Table 3.5. NWC TPIs system

No.	Groups/subgroups	TPIs number
1	Water resources	57
2	Asset	13
3	Customers	19
4	Environment	17
5	Public heath	7
	Total	**113**

However, a glance from the NWC TPIs show that several indicators can apply for WSS in developing countries, especially very useful in areas facing water shortage or droughts. For instance, such system provides a comprehensive picture in the interrelationships among different water resource indicators from surface water, ground water, desalination, recycling water, potable and non- potable water to storm-water indicators. Besides, comparing with above-mentioned systems, greenhouse gas emissions from each activity of a WSS are introduced in environment group.

3.2.5 Other PIs systems

Apart from above-mentioned PIs systems, some other organizations have also developed PIs systems to evaluate WSS performance along with various objectives such as Office of the Water Services of United Kingdom and Wales (OFWAT, 2012), American Water Works Association (AWWA, 2008), National Research Council of Canada (NRC, 2010), and Canadian Standards Association (CSA, 2010). Generally speaking, these systems are indeed very comprehensive and provides a deep insight to the interrelationships between different components of WSS relevant to specific conditions.

For example, OFWAT (2012) provides 14 key indicators as a format that sets out information transparently for water undertakings in United Kingdom and Wales reporting annually whilst AWWA (2008) introduces 31 indicators grouped into 4 groups comprising organizational development, customer relations, business operations, and water operations which seem to be highly suitable for the benchmarking process in North American water utilities but might not be directly applicable for detailed performance assessment with respect to specific requirements (e.g., water source and watershed characteristics) of any S-WSSs (Haider, et al., 2014). In AWWA PIs system, many PIs related to environmental and water resources have not been addressed.

On the other hand, a PIs system proposed by National Research Council of Canada consists of 37 indicators provide detailed information regarding environmental, public health, social, security, and economic performance, but indicators related to physical, and operational aspects of a water utility have not been taken into consideration (NRC, 2010).

3.2.6 Conclusions

Agencies and organizations in the world have developed many performance evaluation systems (PES) – a toolkit for evaluating efficiency of WSS, which includes performance indicators (PIs) to measure efficiency of all aspects of WSS. The current PES provide the huge number of PIs covering most possible aspects of WSS. Each system has been proposed for a specific objective. However, many characteristics of IWS have been not mentioned in these systems. For example, in developing world, the small-sized WSS due to limitation of available conditions (e.g. water scarcity and/or infrastructure constraints) often supplies water some hours per day contingent on available sources and customers' demand, which leads to the presence of private tanks and float valves inside water users' buildings to storage water during the period without supplying water of services. The non-continuous operation causes many unwanted consequences such as decrease of water quality and harmful effects on facilities. Besides, the presence of private tanks (maybe with float valves) not only changes hydraulics' behavior in water distribution system, but also influence negatively on water quality and inaccurate operation of customer meters.

Apart from above-mentioned challenges, small-sized IWS (S-IWS) in developing countries suffers much more difficulties than medium and large ones such as low capital and operation costs, poor physical asset, lack of control and measurement devices, missing data, and so on. This triggers a lot of difficulties for management and operation of S-IWS. Many specific researches also mentioned the problems of discontinuous supply. However, there have not been any researches dealing with this problems for S-WSS comprehensively.

Consequently, so as to apply these systems for developing countries, picking up suitable PIs from above-mentioned PIs contingent on taking real conditions into consideration is indispensable. In the next parts of this chapter, some efforts to solve with these differences for developing world will be shown.

3.3 Efforts to deal with the challenges of IWS

As mentioned in section 2.3, IWS causes many unwanted technical consequences for both network system and individual customers. Therefore, to evaluate the technical performance of these systems, it is necessary to consider about these characteristics in whole evaluation progress. Around the world, many researchers have tried to deal with these challenges with various approaches and methodologies from the general to the particular.

3.3.1 New approaches for IWS based on TPIs system of CWS

Some researchers proposed TPIs system for IWS based on available ones that mentioned in section 3.2 and supplement some new TPIs suitable with IWS condition. For example, Kanakoudis, et al., (2011) based on the special conditions of the Mediterranean area to pick up 75 PIs from 170

IWA PIs, and simultaneously also proposed 11 PIs derived from existing IWA ones and 30 new proposed PIs to solve special issues of WSS in this area. These new 41 PIs mentioned the influence of material and diameter of pipe on real losses; the presence of roof tank on apparent losses; non-revenue water index follow connections and/or the length of mains; the mains failures per type of main as well as energy consumption, carbon footprint, etcetera. However, some PIs from 41 above-mentioned ones seem to be not exact reflect of water loss components. For example, PIs of apparent losses per number and volume of total roof tank, apparent losses come from many reasons such as water theft, intrinsic inaccuracy of water meter, data failures in collecting and calculating data process, not only from roof tanks. Besides, apparent losses due to roof tank only occurs if that roof tank installs float valve to stop collecting water from WDN when roof tank full.

In 2014, Haider, et al summarised and analysed the existing PIs systems, after that, evaluated the applicability of these systems for small and medium-sized WSS in developing countries follow criteria: understandability, measurability, comparability, simplicity, comprehensiveness, and overall applicability. The assessment consequence reveals that IWA PIs system seems to be the most suitable system for with a comprehensive classification system. Afterwards, on the basic of characteristics and status of small and medium-sized WSS in developing countries such as scarce data, limitation of fund, technique, equipment, and trained personnel that require PIs have to be understandability, measurability, and comparability, these authors proposed a PIs system for such WSS follow a stepwise approach based on three levels of indictors comprising start-up, additional, and advanced PIs (follow 6 groups: (1) Water resources and environmental indicators, (2) Personnel and staffing indicators, (3) Operational indicators, (4) Water quality and public health indicators, (5) Quality of service indicators, (6) Financial and economic indicators) depending on the availability of resources and site-specific requirements.

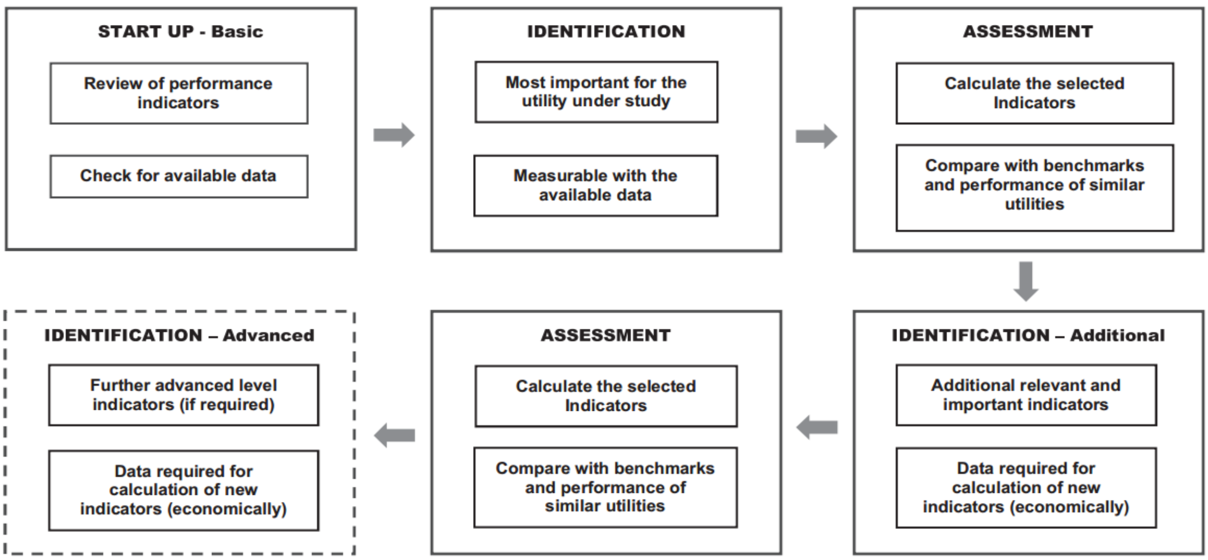


Figure 3.3. Proposed system of PIs to start, proceed, and improve the performance evaluation mechanism in SM-WSS (Haider, et al., 2014)

3.3.2 Impact of network filling-empty process and private tank on inequality of distribution

The impact of network filling-empty process and private tank on inequality of distribution in IWS is evaluated in two factors including water volume distributed and air volume forced to receive follow time and space.

First, to assess inequality of water distribution, most authors have used numerical model to simulate water behavior in filling process and its consequences until now. Liou & Hunt, (1996), who first introduced a model for filling process of pipeline network. Afterwards in 2007 and 2008, comparing intermittent and continuous water supply system, Fontanazza, et al. analyzed WSS under intermittent distribution condition and proposed ten performance indicators in order to identify inequality in water supply, and then applied them for case study in Palermo (Italy). Then, Marchis, et al. (2009 and 2010) presented an unsteady numerical model to analyze the inequalities that take part when intermittent distribution and applied this model for water scarcity scenarios during network-filling process with the presence of private tank. Subsequently, this model were used to determine pressure valve settings to reduce distribution inequality by Freni, et al., (2012). Recently, Lieb, et al., (2016) developed one model of optimizing intermittent water supply in urban pipe distribution networks to minimize damaging pressure transients.

In general, the advantage of using numerical models is that it is easy to define comprehensively the inequality in water volume, discharge and pressure distribution follow time and space are defined among users regarding to various scenario. However, the simulation of water supply network behavior in intermittent condition grapples with many extreme difficulties because the complication of network in filling process, particular with the presence of private tanks and float valves. For instance, status of initial pipeline system are very complex (full water at low positions, and vacuum, or mix at higher ones) at start time of network filling process. Moreover, due to the presence of private tanks, water demand node is not contingent on actual user consumption, but rather on storage capacity of private tanks (size and water level of private tanks at collecting time). Size of private tanks can be identify through house-to-house investigation, but status of initial pipeline network and water level inside private tanks at the beginning of water supply time are impossible to know. In above-mentioned models, to simplify simulation process, there are many assumptions used such as the pipe always remaining full water (Liou & Hunt, 1996) or all of the pipes in the network are initially empty (Marchis, et al., 2010). These hypothesis certainly influence on the accuracy of simulation.

Second, about evaluating inequality of airflow distribution, although there are some studies related to this topic such as David Walter (2017) who implemented an experiment to measure the accuracy of single-jet water meters during filling of the pipe network in intermittent supply, or Fontanazza, et al., (2015) carried out an experimental and modelling analyses to define the effect of water meter age and private tanks on measuring errors, yet, airflow distribution in IWS that leads to under-registration meters at different positions in network filling process have not mentioned in such researches.

In summary, to the authors' knowledge there are not any methodologies which evaluate comprehensively the distribution of both water flow and airflow during network filling process so far.

3.3.3 Impact of float valves and intermittent supply on meter inaccuracy

The meter accuracy is influenced by many factors such as "meter wear and tear, deterioration, buildup of deposits, water quality, water velocities, amount of throughput, environmental issues, effects resulting from handling and installation" (Stoker, et al., 2012). In IWS, independent from above-mentioned factors, the meter accuracy is also dominated by the presence of private tanks and discontinuous operation. The float valve are frequently installed inside the private tank to automatically stop collecting water when the tank is full. The closing process of float valve occurs slowly from the tank nearly full until completely full. "This process reduces flow rates passing through the meter that are lower than the starting point flow of the revenue meter and are not recorded" (Criminisi, et al., 2009). On the other hand, the pipeline system are subjected to vacuum condition on duration of without supplying water. Then, when water is supplied again, water running through the pipe network and the airflow ahead of the arrival of the water happens always at the beginning of the network filling process. This air front is discharged through air valves, leakages in pipeline network and service connections, and thus, through water meters of customers. The water meters that have an impeller on the inside measure amount of water through the kinetic energy of the water flow, which could not recognize the difference between water flow and airflow. The water meters are therefore being inaccurate due to the alternating filing and emptying of the pipe network in intermittent water supply (David Walter, 2017). Therefore, it can be concluded that the two factors that cause the meter inaccuracy are low flowrates during the process of closing the float valve inside the private tank and air volume at the beginning of network filling process.

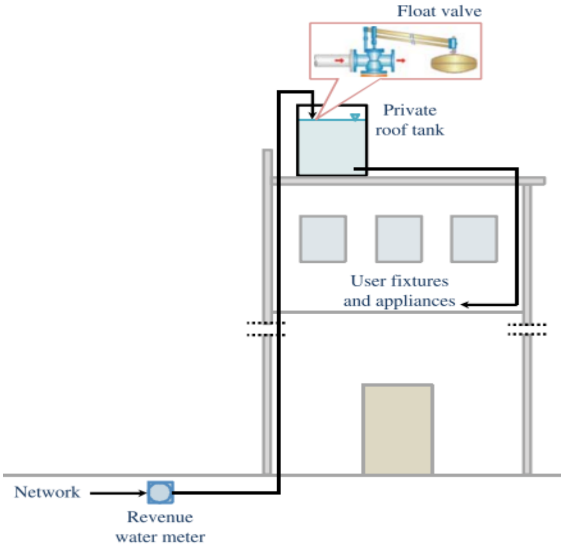


Figure 3.4. A private roof tank with float valve (Criminisi, et al., 2009)

In order to monitoring the meter under-registration from real user on-site, a representative meter group can be selected from all kinds of existing meters regarding to brand, age and design type. Afterwards, field experiments are installed on-site. The devices supporting for the measurement process often include pressure sensors, pressure cell level meter, new and calibrated water meters. The pressure sensor was installed upstream of the revenue meter to measure and record network pressure data. The meters was installed both upstream and downstream of the private tank and the tank water level was measured by the pressure cell level meter (Criminisi, et al., 2009).

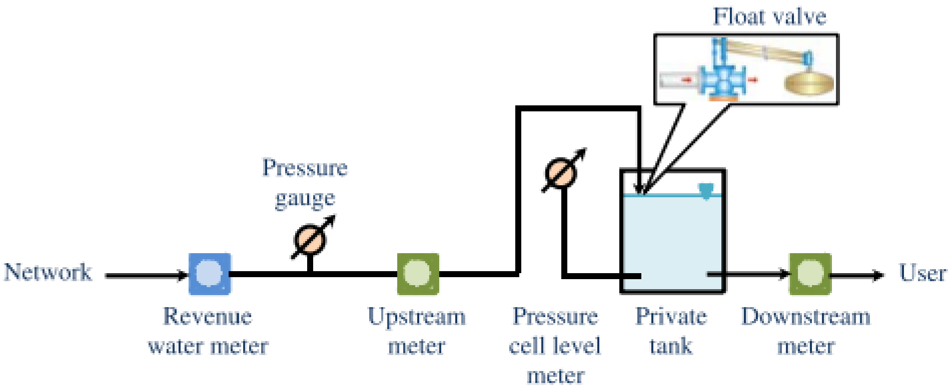


Figure 3.5. A schematic of the monitoring installation (Criminisi, et al., 2009)

In order to assess the influence of private tanks on the metering accuracy in laboratory, Marchis, et al., (2014) implemented experiments at the Environmental Hydraulic Laboratory of the University of Enna (Italy). In these experiments, the network is designed including three loops, nine nodes, eleven pipes, four pumps, one reservoir, one air vessel, six electromagnetic flow meters, and a roof tank with float valve. The experiment is carried out in three types of operation conditions including the presence of constantly filled tanks (the ball valve opens slightly and the tank is rapidly replenished at each water use), the presence of tanks subjected to cyclical filling and emptying processes (simulating a daily intermittent network in which the thank is filled every two days) and the tank used as by-passed. Afterwards, in 2015 and 2016, these author group proposed a new model able to reproduce the tank emptying/filling cycles based on a series of experiments in the laboratory.

3.3.4 Impact of intermittent supply and private tanks on water quality

To evaluate impact of intermittent supply and private tanks on water quality, in general, most researches have been using the method of analyzing samples taken from WSS and water samples inside users' houses. Namely, test parameters are commonly bacterial indicator organisms (e.g., (HPC), total coliform, fecal coliform), free and combined chlorine, turbidity, temperature, PH, TDS, conductivity. Samples are often collected at positions such as supply sources (e.g., water treatment, artesian well), reservoir, transmission pipe, before and after household tank, consumer taps, and point-of-consumption sampling. About time schedule of taking samples, water samples could be taken right after supplying water (first-flush sampling) and during the time of supplying water of service depending on study's objective. The assessment could be carried out only for IWS or together with CWS to express negative influences of intermittent supply and private tanks on water quality. The method of analysing sample was used in many researches in the following.

Table 3.6. Studies about impact of intermittent supply and/or private tank on water quality

No.	Authors	Title	Parameter	Sample location	Sample time
1	(Erickson, et al., 2017)	Water quality effects of intermittent water supply in Arraijan, Panama	Turbidity, free chlorine, total coliform and E. coli bacteria, aerobic spore-forming bacteria, HPC bacteria	Transmission pipe, zone entrance station, zone downstream station, household tap	First-flush sampling and during the time of supplying water (August 2014 to August 2015)
2	(Boakye-Ansah, et al., 2016)	Inequalities in microbial contamination of drinking water supplies in urban areas: the case of Lilongwe, Malawi	Temperature, turbidity, pH, free and total chlorine, E. coli and total coliforms	Water treatment, Reservoirs, household taps, kiosks and water storage facilities	During the time of supplying water (between November 2014 and January 2015)
3	(Kumpel, et al., 2013)	Comparing microbial water quality in an intermittent and continuous piped water supply	Total coliform, Escherichia coli, turbidity, free chlorine, and combined chlorine.	Reservoirs, consumer taps, and point-of-consumption sampling	During the time of supplying water (between November 9, 2010 and November 17, 2011)
4	(Machdar, et al., 2013)	Application of Quantitative Microbial Risk Assessment to analyze the public health risk from poor drinking water quality in a low income area in Accra, Ghana	Escherichia coli O157:H7, Campylobacter, Rotavirus, Cryptosporidium and Ascaris	Household water storages, private tap connections, water sachets, water tankers, and communal points: public taps, public wells and communal tanks	During the time of supplying water
5	(Matsinhe, et al., 2004)	The effects of intermittent supply and household storage in the quality of drinking water in Paputo	Free and total residual chlorine, turbidity, bacteria, solids, temperature, pH, TDS, conductivity	Treated water, distribution centres, before and after household tank	During the time of supplying water usually between 7.30 a.m. and 2.00 p.m. (from November to December 2004)
6	(Tokajian, et al., 2003)	Water quality problems	pH, HPC bacteria,	Supply source (artesian well),	During the time of supplying

No.	Authors	Title	Parameter	Sample location	Sample time
		associated with intermittent water supply	temperature, coliforms and E. coli, total chlorine, turbidity	reservoir, distribution network, household tanks	water over a period of two years (1999-2000)

Water quality at customer connections often has a big difference at the beginning of collecting water (first-flush period) and later period (routine). In first-flush period, water quality are degraded significantly due to stagnant water inside pipe, intrusion and backflow through leakages. To examine water quality in this time, ideally, series of grab samples during the first 2 h of supply: samples for total coliform, E. coli, and HPC bacteria were collected from the first water that came out of the tap and after 1, 5, 10, 20, 30, 45, 60, 80, 100 and 120 min of supply. Samples for aerobic spore-forming bacteria were collected after 1, 5, 20, 60 and 120 min of supply (Erickson, et al., 2017). Afterwards, water quality gradually become better and stably. To evaluate water quality in this time, routine samples were collected during the time of supplying water (Erickson, et al., 2017; Kumpel, et al., 2013; Machdar, et al., 2013; Matsinhe, et al., 2004; Tokajian, et al., 2003; Boakye-Ansah, et al., 2016).

3.3.5 Impact of intermittent supply on quicker asset deterioration and real losses

In IWS, filling and draining network process always occur in water supply cycles. Namely, air font ahead will move at high speed during at the beginning of restarting supply, which leads to water hammer phenomenon in pipelines. Moreover, pipeline system are at atmospheric pressure when water off, followed by unbalance between pressure inside and outside pipe walls. Besides, distribution under IWS is a good condition for wear and tear. During the last decades, some researchers have developed various methods to look for evidences of intermittent supply relating to asset deterioration and real losses. For example, Agathokleous, et al., (2016) utilized survival analysis, based on an eight-year dataset (2003-2010), to proof that there is a significant increase in the number of water-leak incidents and a deterioration of the network condition under intermittent supply.

3.3.6 Conclusions and further study

The performance evaluation systems for CWS are quite adequate while defining tools for WSS under intermittent supply condition in developing countries have been suffering many challenges due to its particular characteristics. Many researches carried out to solve this problems. However, there are some issues that have not completely been solved yet.

- Insufficiency of TPIs reflects the relationship amongst critical factors under IWS position. For example, it has still not had TPIs of the change of water quality along with pipeline system as well as after and before private tanks, or air volume distribution at various positions in pipeline system.

- There are a series of TPIs proposed for performance evaluation of WSS, but the methods to define corresponding variables have not been pointed out in these proposes although some of them mentioned kind of necessary variables for calculation progress of TPIs.

Collecting variables is a costly and time-consuming process that needs great efforts from all stakeholders related to WSS. For small-sized WSS, this process will face more extreme difficulties due to missing data from operation and management progress, lack of support devices for collecting and measuring data, and limitation of applying state-of-the-art methods as well.

In the next chapter, a technical performance evaluation system (TPEs) for S-IWS in Vietnam will be proposed based on available ones in the world and Vietnam S-IWS's characteristics.

4 Propose TPES and benchmarking for S-IWS in Vietnam

Due to the limitation of data, control and management devices as well as support devices during the process of evaluation. The evaluation process should be broken into two periods first year and next years. In the first year, the basic data necessary for evaluation are mostly not available such as physical asset of water distribution network and physical asset inside customers' houses, water demand, customer information, and so on. Thus, it will take much time and great effort for field investigation along with the pipeline network and house-to-house investigation to collect the data. At the same time, a program of record and management needs to be installed to record indispensable data for next years of evaluation. By dint of this, the PIs in this year will include basic indicators. The next years of evaluation will be take less time and efforts thanks to inheriting data from the first time and data recorded from new program of management. Some indicators of operation group can be added in the next times of evaluation.

4.1 General approach

The proposal process of technical performance evaluation system (TPES) for S-IWS in Vietnam includes some steps as the following:

Step 1: Develop the TPES for S-IWS in Vietnam. Some TPIs is selected from available TPIs around in the world such as some TPIs related to boundary conditions and water losses. Some TPIs could be kept as its origin or modified to be suitable with Vietnam conditions. Other ones are proposed based on Vietnam S-IWS's characteristics including TPIs about inefficiency of physical asset, inequality of water and air distribution, and water quality.

Step 2: Define requirement variables data from TPES. The data can be collected from water utilities, national data, and other projects and so on. The process of analysing collected data enable to identify missing data.

Step 3: Propose suitable methods to collect missing data. Methods to collect will be proposed based on each kind of missing data.

Step 4: Evaluate the technical performance of S-IWS based on TPES and benchmarking. The calculated PIs from TPES will be compared with the benchmarking to determine current situation of WSS.

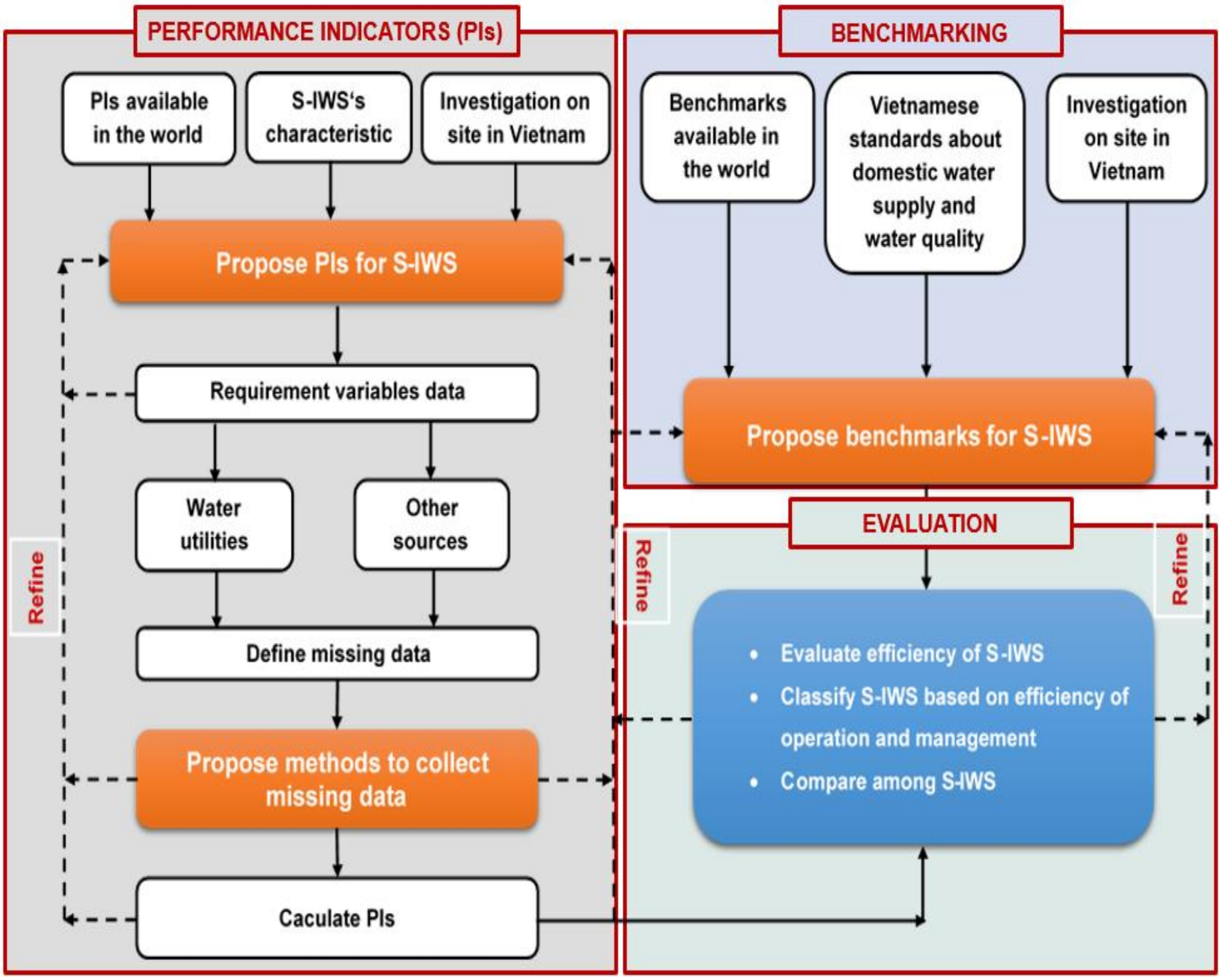


Figure 4.1. General approach to propose TPES for S-IWS in Vietnam

TPIs will be refined to be suitable with real condition during evaluation process. The whole process of proposing TPEs is shown in Figure 4.1

4.2 Propose technical performance evaluation system

Generally, the key PIs system to assess performance of WDN can be separated into three groups:

- The boundary conditions: Water available resources and water demand;
- The performance of total system: Infrastructure asset of WDN and infrastructure asset inside households interacting with WDN, coverage of water supply service, operation time, and water losses;
- The system performance impact on individual consumers: Water quality and inequitable distribution.

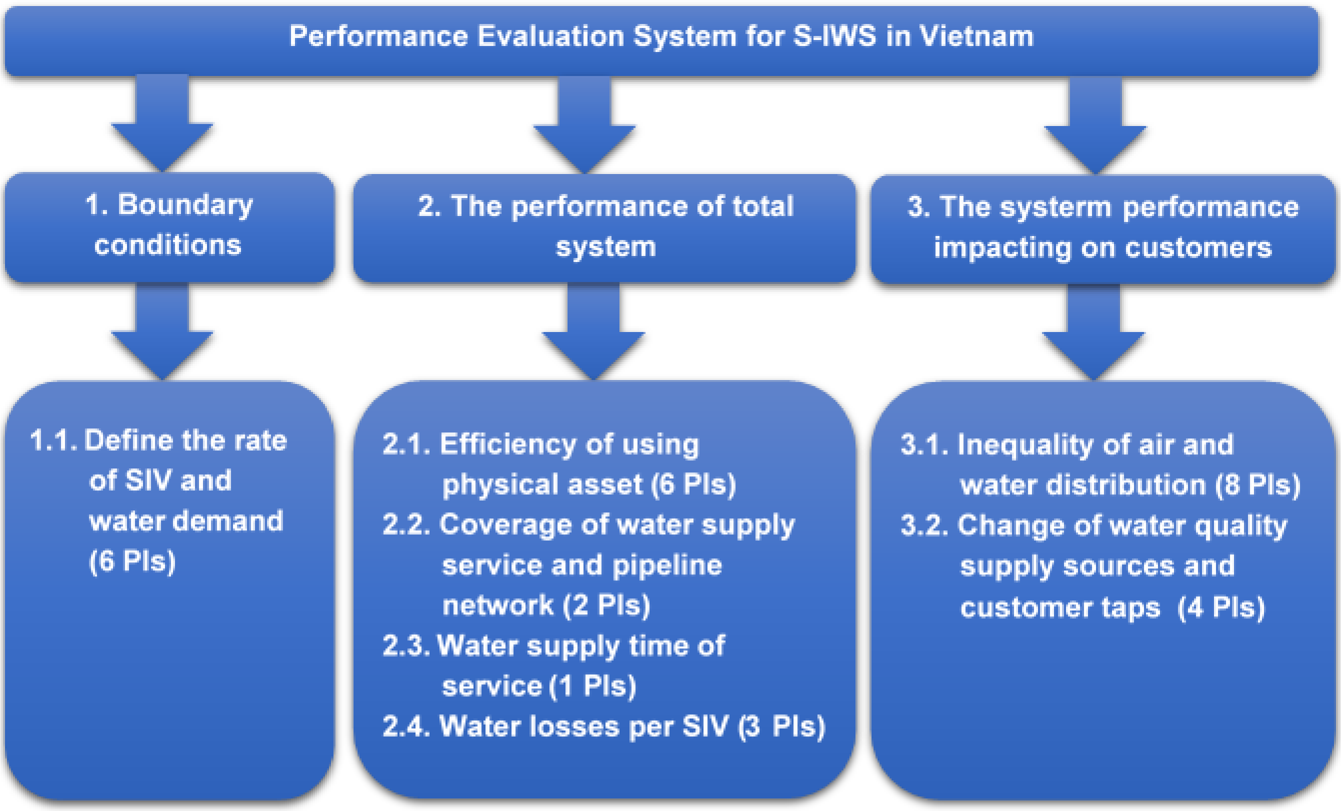


Figure 4.2. Structure of TPEs for S-IWS in Vietnam

4.2.1 The boundary conditions: Water available resources and water demand

The water resource of Vietnam is quite plentiful comprising surface water (the total average yearly about 830 billion m^3), groundwater (estimated total 'groundwater potential' of almost 63,000 million m^3 per year) and rainfall (average annual approximately 1940 mm/year) (Brown, et al., 2008). With its population over 95.6 million (2017) (Source: http://worldpopulationreview.com), Vietnam has total average yearly water nearly 9560m^3 per capita. Additionally, total water amount of water supply sector solely accounts for 3 ÷ 5% of total demand of economic sectors in Vietnam (Brown, et al., 2008). It could be concluded that total annual water resource of Vietnam outstrips the demand of water supply sectors.

Paradoxically, in spite of above favorable conditions with available water resource, many WSS has been grappling with water scarcity because of many reasons. One of main causes is the distribution of water resources over the year unevenly. For instance, the dry season often lasts between 7 and 9 months with rainfall only of about 20 - 30% of the annual rainfall whilst the rainy season lasts nearly 3 ÷ 5 months, constitutes about 70% to 80% of the annual rainfall (Nguyet et al., 2012). Thus, for many WSS, total water system input volume (SIV) is much bigger than water demand over year, but not enough in dry season. This problem is especially true for S-WSS which is often located at remote areas or/and extreme conditions of topography and geography. Karst areas are a typical example. Temporary surface runoffs generally are formed only after heavy rains. Due to the high infiltration rates of Karst, water usually assembles in underground Karst cave networks forming underground water resource, which is potential resources for the water supply in Karst areas. Therefore, in accessing ability of available water sources, apart from total capacity of water resources over year, the capacity during the period of water scarcity should be taken into consideration. Besides, the ability of supplying water of supply sources should be also evaluate in a comprehensive view from system input volume, water resource availability to water resource potentiality.

Table 4.1. Propose PIs of boundary conditions

No.	Indicator	Formulation	Origin
BC_{11}	Rate between water system input volume (SIV) and water demand in one year (%)	[(SIV in a year)/(Volume of water demand follow water supply standard of service area in a year)] x 100	New
BC_{12}	Rate between SIV and water demand in dry season (%)	[(SIV in dry season)/(Volume of water demand follow water supply standard of service area in dry season)] x 100	New
BC_{21}	Rate between available water resources and SIV in one year (%)	[(Availability of water resources in one year)/(SIV in a year)] x 100	IWA
BC_{22}	Rate between available water resources and SIV in dry season (%)	[(Availability of water resources in dry season)/(SIV in dry season)] x 100	New
BC_{31}	Rate between potential water resources and water demand in one year (%)	[Potentiality of water resources in one year)/(Volume of water demand follow water supply standard of service area in a year)] x 100	New
BC_{32}	Rate between potential water resources and water demand in dry season (%)	[Potentiality of water resources in dry season)/(Volume of water demand follow water supply standard of service area in dry season)] x 100	New

For the reasons above-mentioned, indicators of boundary condition group will include water system input volume, availability and potentiality of water sources comparing with water demand of service area in one year and in dry season. Namely, this group consists of six indicators comprising: BC_{11} and BC_{12} comparing SIV and water demand, BC_{21} and BC_{22} comparing SIV and availability of water resources, BC_{31} and BC_{32} comparing potentiality of water resources and water demand. Name and calculation formulation of each indicator is shown in Table 4.1.

4.2.2 The performance of total system

4.2.2.1 Physical asset of distribution system

Physical asset of water distribution network generally includes pipeline network, tanks, valves, public tank, reservoir, and other devices. In S-IWS, these asset are frequently deteriorated or degraded after short time of operation because of various reasons like lack of investment for renovation and rehabilitation, unsuitable design, operation far from design, untrained personnel, low awareness of staffs and citizens about protecting public asset. Besides, the drained water source is another reason lead to the waste of construction. Dong Van city is a typical example. There were five water sources which supplied water for Dong Van city in the past. Three of them have drained until now. As a result, they wasted hundreds of (VND) billions of investment for constructing water collection tanks, pipes (source: investigation in 2016). This triggers the waste of governmental fund, like a vicious cycle, the investment for small-sized WDN becomes less and less.

Table 4.2. PIs of physical asset

No.	Indicator	Formulation	Origin
	Pipelines		
PS_1	Pipes in use (%)	(Total length of pipes in use)/(total length of pipes of WDN) x 100	New
PS_2	Coverage of WDN (%)	(Total households where WDN reach)/(total households in service area) x 100	WB
	Tanks		
PS_3	Volume of public tanks in use (%)	(Total volume of public tanks in use)/(total volume of public tanks of WDN) x 100	New
PS_4	Water storage capacity of public tanks in use (days)	[(Total volume of public tanks in use)/(SIV in one year)]x (365 days)	IWA
	Valves		
PS_5	The number of valves in use (%)	(Total valves in use)/(total valves of WDN) x 100	New
	Other devices		
PS_6	The number of other devices in use (%)	(Total other devices in use)/(total other devices of WDN) x 100	New

Therefore, the assessment of physical asset needs to focus on percentage of pipe, tank and valve being in use and coverage of WDN. Namely, indicators PS_1, PS_3, PS_5 and PS_6 provide the rate of pipes, tanks and valves and other devices in use while PS_2 shows coverage of pipeline network in service area. The indicator PS_4 will evaluate maximum water storage capacity of public tanks to supply water for WDN in case of supply sources without supplying water. All these indicators will reveal the waste of current facility and support for a plan of maintenance and rehabilitation as well as improving WDN.

4.2.2.2 Coverage of water supply service

Small-sized WSS frequently grapples with many difficulties like physical water scarcity, asynchronous infrastructure asset, lack of investment for renovation and rehabilitation, untrained personnel, which leads to limited quality of water supply service (not enough water in time and space, bad water quality). Therefore, inhabitants who live in these areas have to look for themselves other water resources (rainfall, drilled well, and etc.) to supplement or/and instead of water from WSS during water scarcity period. As a result, water users have to use different water sources to have enough water over year.

Table 4.3. Propose PIs for coverage of water supply service

No.	Indicator	Formulation	Origin
PS_7	The rate of households connected with WSS per total households (%)	(Total households connecting with WSS)/(total households in service area) x 100	IWA, WB
PS_8	Rate between households using 100% water from WSS and households connecting with WSS (%)	(Total households using 100% water from WSS)/(total households in service area) x 100	New

For this reason, water users could be divided into three groups in according to water sources: (1) 100% using water from WSS (where water from WSS is the unique water supply source or advantaged locations), (2) using water both from WDN and other sources (where is diverse water supply sources or/and disadvantaged locations), (3) only using water from other sources (where is diverse water supply sources or/and disadvantaged locations). Most households using many sources will only use water from WSS when other ones are empty or very bad water quality comparing water quality from WSS. Thus, if only defining % household using water from WSS will not reflect exactly the number of households consuming reality water from WSS.

Taking such characteristics in proposing PIs for coverage of water supply service into consideration, this subgroup will include two indicators PS_7 and PS_8. For example, the indicator PS_7 define rate of households connected with WSS and total households while PS_8 will identify number of households using 100% water from WSS. Name and formulation to calculate indicators of this subgroup is presented in Table 4.3.

4.2.2.3 Water supply time of service

Almost of all small-sized WSS in Vietnam is operated intermittently. It means that operation time is less than 24 hours per day. Water supply time of service depends on many factors such as availability of water sources, scale of WSS, capacity of pump station (if have), characteristics of pipeline network (pipe diameter, difference of elevation, water demand of customer, and so on. Normally, the longer water supply time of service is, the better the quality of service is.

Table 4.4. PIs of water supply time

No.	Indicator	Formulation	Origin
PS_9	Average operation time of water supply service per day (hour/day)	(Total hours of water supply service in a year)/365	IWA

Therefore, the indicator of water supply time of service (PS_9) will define average operation time of water supply service per day. This indicator is a basic parameter to assess negative impacts of intermittent supply on WSS and individual customers.

4.2.2.4 Water losses

Water losses management plays an important role in both economy and environment. The definition of total water losses and its components are necessary for assessing the amount of water that can be saved, as well as looking for methods to improve performance of WSS. However, in fact, it has been being never easy to deal with the problem related to water losses because of its complexity.

Generally, water losses can be separated into two components apparent losses and real losses. Apparent losses come from unauthorized consumption and meter inaccuracy. In a WSS operated intermittently, apart from internal inaccuracies of meters, there are some other causes leading to inaccuracy of measuring water consumption at households such as airflow at the beginning of network filling process and float valves when private tank nearly full. Therefore, the process of calculating apparent losses will concentrate on its components caused by various factors including: (1) apparent losses due to unauthorized consumption, (2) apparent losses due to internal inaccuracies of meters, (3) apparent losses due to airflow at the beginning of network filling process, and (4) apparent losses due to the present of float valves when private tank nearly full.

Real losses are the result of leakages on components of WSS such as leakages from tanks/reservoirs, transmission mains, and distribution network. Defining real losses on WSS is far from easy because almost of all pipelines and connections are underground. Thus, real losses will be the last component calculated in water balance (see section 4.4.6).

Table 4.5. PIs of water losses

No.	Indicator	Formulation	Origin
PS_{10}	The rate between Non-Revenue Water and SIV (%) (%)	(Total volume of Non-Revenue Water in one year)/(Total volume of water input in one year) x 100	IWA
PS_{11}	Infrastructure leakage index: ILI (-)	(Total volume of real losses in one year)/(Unavoidable real losses in one year)	IWA
PS_{12}	Apparent loss index: ALI (-)	(Total volume of apparent losses in one year)/(5% of water consumption recorded by water meter in one year)	IWA

Normally, reducing apparent losses can be achieved through a suitable process of operation and management while decreasing real losses is much more difficult because this problem relates to whole physical asset of WSS. In fact, real losses always happen in every WSS and can never be completely eliminated. A certain minimum amount of real losses will exist, which is referred to as the unavoidable real losses. Thus, the ratio between current real loss and unavoidable real losses will represent the potential for reducing real water losses further. The equation to calculate unavoidable annual real losses (UARL) is introduced by Lambert, et al., (1999) in the following:

$$UARL = (18xL_N + 0.8xN_C + 25xL_P) \times P_A \quad \text{(Equation 4.1)}$$

Where:

UARL (l/day) : Unavoidable annual real losses

L_N: (km) : Network length (without service connection pipes)

N_C (-) : Number of service connections

L_P (km) : Length of private service pipes after the property line

P_A (m) : Average operating pressure

In order to evaluate the performance of managing water losses, indicators of this group will compare total water loss and two its components (apparent losses and real losses) with water system input volume. In addition, indicator of infrastructure leakage index (ratio between current real losses and unavoidable real losses) also includes in this subgroups. Besides, in IWS, air volume at the beginning of network filling process often accounts for much bigger proportion than other components of apparent water losses. Hence, the air volume will be evaluated independently from other components.

In brief, the indicators of water losses group include three indicators (PS_{10}, PS_{11}, PS_{12}, PS_{13} and PS_{14}). Namely, PS_{10} and PS_{13} compare total water losses and real losses with water system input volume while PS_{11} and PS_{12} evaluate air volume and other components of apparent losses. Finally, PS_{14} reflect the gap between current real losses and unavoidable real losses. Name and formulation of each indicator are presented in Table 4.5.

4.2.3 The system performance impacts on individual customers

4.2.3.1 Inequity of distribution

The inequitable distribution in WSS reveals in many respects including time of collecting water of customers per day (time of water coming to connections, available time of water at every connection), air volume forced to collect at the beginning of network filling process, and average water flow at each connection. Because of these, water users located at disadvantaged zones such as high or/and far zones have to look for solutions themselves to supplement the water deficiency over year. There are some common solutions such as using many water sources at the same time (water from cliffs, drilled well, and rainfall), using less water (less consumption), or building bigger private tank. Therefore, indicators of inequality will compare the difference of available time collecting water, water and air volume, the percentage of water users connecting with WSS, consumption level, and volume of private tank at different zones.

To evaluate inequality of distribution, WSS should be divided into different zones depending on elevation (e.g. highest, high, local high, little high, little low, local low, low, and lowest), position (e.g. near supply sources, middle, end zone), distance to supply sources, pipe diameters, pipe material, important level of zone, and so on. Then, the difference of indicators among different zones reveals inequality of distribution. Normally, it can be estimated that zones located disadvantaged points (e.g. high and end zone) will have smaller amount of water flow, but forced to receive larger air volume at the beginning of network fulfill process, and shorter time of collecting water comparing other zones. However, the indicators will provide specific numbers and a comprehensive picture of inequality among zones.

There are eight indicators proposed in this group including IC_1, IC_2, IC_3, IC_{41}, IC_{42}, IC_{51}, IC_{52}, and IC_6. For instance, IC_1, IC_2 and IC_3 belonging to indicators of cause group (the system impacting on individual customers) will evaluate available time of water, water flow and air volume at different zones. On the other hand, IC_{41}, IC_{42}, IC_{51}, IC_{52}, and IC_6 belonging to indicators of effect group (solutions of customers to have enough water over year) assess the difference of consumption level, private tank volume, and number of households connecting with WSS at various zones. Name and formulation of indicators in this group is presented in Table 4.6.

Table 4.6. PIs of inequitable distribution

No.	Indicator	Formulation	Origin
IC_1	Rate between available time of water at zones and supply time of system (%)	Available time of water at different zones will be defined from field experiments	New
IC_2	Rate between average water flow at zones and average water flow of system (%)	(Total water volume collected at measure points)/(total time of collecting water)	New
IC_3	Rate between air volume and consumption at different zones comparing with system average (%)	(Total air volume)/(Total consumption measured by customer meter) x 100	New
IC_{41}	Rate between households connecting with WSS and total households at different zones (%)	(Number of households using water from WDN)/(Total number of households in area) x 100	New
IC_{42}	Rate between households using 100% water from WSS and total households at different zones (%)	(Number of households using water from WDN)/(Total number of households in area) x 100	New
IC_{51}	Consumption recorded by meter at different zones (m^3/ca/day)	(Total consumption measured by customer meter)/(total population) x 100	New
IC_{52}	Real consumption at different zones (m^3/ca/day)	(Total real consumption)/(total population) x 100	New

No.	Indicator	Formulation	Origin
IC_6	Volume of private tank per household at different zones (m^3/conn)	(Total volume of private tank)/(Number of households) x 100	New

4.2.3.2 Water quality

In order to evaluate the impact of IWS and private tank on water quality in distribution network, test parameters, time schedule and position of samples in ideal condition should be defined in the following:

Test parameters: Pursuant to national technical regulation on domestic water quality QCVN 02:2009/BYT, the 14 parameters of domestic water need to check including color, taste, turbidity, residual chlorine, PH, ammonia, total iron, permanganate, $CaCO_3$, chlorine, fluorine, total arsenic, total coliform, e. coli. The standard of water quality pursuant to this regulation is shown in Table 4.7. It is the best way if all these parameters are checked for evaluation process of water quality.

Table 4.7. National technical regulation on domestic water quality QCVN 02:2009/BYT

No.	Parameter	Unit	Maximum allowable limit
1	Color	TCU	15
2	Taste	-	No special taste
3	Turbidity	NTU	5
4	Residual chlorine	mg/l	0.3÷0.5
5	PH	-	6.0÷8.5
6	Ammonia	mg/l	3
7	total Iron	mg/l	0.5
8	Permanganate	mg/l	4
9	$CaCO_3$	mg/l	350
10	Chlorine	mg/l	300
11	Fluorine	mg/l	1.5
12	Total arsenic	mg/l	0.01
13	Total coliform	MPN/100ml	50
14	E. Coli	MPN/100ml	0

However, in fact, selecting test parameters will depend on some factors such as budget, time, availability of devices and chemicals for test process. Some parameters such as total coliform and e. coli, turbidity should be prioritized to choose because they represent the spread of common underground contaminated sources (e.g. dirties, mud, bacteria). Besides, some WSS are put in special areas where can contain potential underground contaminated sources or industrial areas (e.g. arsenic, pesticides) which can go in pipeline network. Then, parameters related to the contaminated sources should be involved in test progress.

Time schedule: Most pipelines is located underground and near sewage ditch in Vietnam. Thus, if WSS is operated intermittently, these pipelines will be subjected to vacuum condition after supply hours, which can cause groundwater infiltration into the pipelines with contamination of the supply or pipes deformation. Besides, the present of private tanks inside households also have both positive and negative effects on water quality. For instance, roof tanks because of being located at the top of houses often rise water temperature, which can make a better environment for proliferating bacteria. However, roof tanks help dirt and impurities deposit in water. Therefore, to evaluate comprehensive influence of IWS and private tank on water quality, water samples should be taken at least 2 times of supplying water:

First time – as soon as water coming to customers: The target of this time is to check water quality of stagnation water in pipeline network during time of without supplying water. It is very useful for estimating leakage positions and contaminated sources around pipes. Besides, from the test result water quality at supply sources, stagnation water, and private tank are also compared.

Second time – during the period of supplying water: The target of this time to check the impact of pipeline network and private tank during running time of service on water quality. The test result is also useful for estimating leakage positions and contaminated sources around pipes if the value of test parameters fluctuates rapidly at some specific points.

Test points: Selecting positions of taking water samples are very important to evaluate the influence of IWS on water quality. Thus, choosing test points should base on difference of elevation in pipeline network, change of pipe diameter and material, diagram of pipeline network, and experience of operation and management staffs. Hence, test positions should include supply sources, points of changing elevation and/or direction and/or pipe diameter, branch points, end points of WSS, pipe positions where are estimated to occur leakages. At each test point, water samples should be taken both before and after private tank to evaluate the influence of private tank on water quality.

Table 4.8. PIs of water quality

No.	Indicator	Formulation	Origin
	Change of water quality in pipeline network		
IC_7	The rate of water quality parameters as soon as water coming to test points and water quality parameters at supply source (%)	(Water quality parameters of water samples as soon as water coming to test points)/(Water quality parameters at supply source)x100	New
IC_8	The rate of water quality parameters at test points in running time of service and water quality parameters at supply source (%)	(Water quality parameters of water samples at test points in running time of service)/(Water quality parameters at supply source)x100	New
	Change of water quality before and after private tank		
IC_9	The rate of water quality parameters after and before private tanks as soon as water coming to private tanks (%)	(Water quality parameters of water samples at private tank taps before water from WDN coming)/(Water quality parameters of water samples before private tanks as soon as water coming to private tanks)x100	New

No.	Indicator	Formulation	Origin
IC_{10}	The rate of water quality parameters after and before private tanks in running time of service (%)	(Water quality parameters of water samples at private tank taps in running time of service)/(Water quality parameters of water samples before private tanks in running time of service)x100	New

The indicators of changing water quality in pipeline network will compare water quality in WDN and at private tanks with water quality at the supply source. Thus, these indicators provide a picture of changing water quality from supply sources to customers' private tanks. The results can be shown in tables or/and charts to present visual images about changing water quality in pipeline network. Namely, the indicator IC_7 will reflect the rate of water quality parameters as soon as water coming to test points and water quality parameters at supply source. It means that IC_7 will compare water quality at supply source with stagnation water during the time of without supplying water. The indicator IC_8 compares water quality parameters at test points in running time of service with water quality parameters at supply source. The target of IC_7 is to evaluate the impact of WDN on water quality during the time of without supplying water while IC_8 reflects this impact in running time of service. On the other hand, the indicators IC_9 compare water quality of stagnation water in WDN with water quality of the remaining water of private tanks from previous day, and IC_{10} compares water quality before and after private tanks during the time of running service. The target of IC_9 is to assess the influence of stagnation water in WDN on decrease of water quality at private tanks IC_{10} is to evaluate the impact of private tanks on water quality during the running time of service. Name and formulation of indicators of water quality are presented in Table 4.8.

4.3 Propose benchmarking

The benchmarking is important to evaluate the operation performance and classify WSS. To provide a comprehensive picture for evaluation process, the benchmark system will be built based on the rules that each performance indicator will be marked from 1 to 4 with weight depending on its important level. Average score of WSS is arithmetic mean of all PIs with relevant weight. The proposal of benchmarking bases on author's experience during the time of working on-site with WSS and some Vietnamese standards about domestic water supply and water quality such as national technical regulation on domestic water quality QCVN 02:2009/BYT of Ministry of Health and Distribution System and Facilities Design Standard number TC33/2006 of Ministry of Construction.

4.3.1 Boundary conditions (BC)

The target of benchmark for boundary condition group is to compare the capacity of water source with water demand. Mark levels go from 1 to 4 depending on each indicators (see Table 4.9). Namely, if SIV during the time of water scarcity and in whole year are over water demand (>100%), the proposed mark will be 4. And then, if SIV is smaller than water demand with the different levels such as (≥100÷90%), (≥90÷70%) and (≤70%), the proposed mark is 3, 2, and 1, respectively. Similarly, the availability of water sources (BC_{21}, BC_{22}) are scored from 4 to 1 equivalent to different levels (>300%), (≥300÷200%), (≥200÷100%), and (≤100%). In the same way, the potentiality of water sources (BC_{31}, BC_{32}) are scored from 4 to 1 equivalent to different levels (>500%), (≥500÷300%), (≥300÷200%), and (≤200%).

The important level of each indicator will be assessed by weight. For example, Vietnam is the plentiful country of water in annual total rainfall, but not distributed evenly throughout the year. The dry season often lasts eight months, from October to May, with rainfall only of about 15 - 20% of the annual rainfall. The rainy season lasts four months, from end of May to end of September, and constitutes about 80% to 85% of the annual rainfall (Nguyen, et al., 2012). Thus, the indicators reflect the capacity of supply source in this time to be much more important than other ones. For this reason, the weight of indicators during the time of water scarcity (BC_{12}, BC_{22}, and BC_{32}) is proposed to be twice bigger than the weight of indicators in whole year (BC_{11}, BC_{21}, and BC_{31}), respectively. Besides, the indicators of potential water sources is proposed lower in weight than their availability because the evaluation system concentrates on current position of WSS and the potential sources is only reference information for an improvement plan in the future.

Table 4.9. Benchmarking of boundary conditions

No.	PIs / Mark	A (4)	B (3)	C (2)	D (1)	Weight
BC_{11}	Rate between water system input volume (SIV) and water demand in one year (%)	>100%	100÷90%	90÷70%	<70%	3
BC_{12}	Rate between SIV and water demand in dry season (%)	>100%	100÷90%	90÷70%	<70%	6
BC_{21}	Rate between available water resources and SIV in one year (%)	>300%	300÷200%	200÷100%	<100%	2
BC_{22}	Rate between available water resources and SIV in dry season (%)	>300%	300÷200%	200÷100%	<100%	4
BC_{31}	Rate between potential water resources and water demand in one year (%)	>600%	600÷300%	300÷200%	<200%	1
BC_{32}	Rate between potential water resources and water demand in dry season (%)	>600%	600÷300%	300÷200%	<200%	2

The average mark of group BC will be calculated follow equation 4.2.

$$\text{Average mark of BC} = \frac{3BC_{11} + 6BC_{12} + 2BC_{21} + 4BC_{22} + BC_{31} + 2BC_{32}}{18} \quad \text{(Equation 4.2)}$$

The capacity of water resources will evaluate in four classes including sustainable, acceptable, water scarcity and extreme water scarcity equivalent to mark levels 4, 3÷4, 2÷3, and 1÷2. WSS with mark 4 means that SIV meet the demand at the time of evaluation and the potential water sources is guarantee for extend plan of WSS in the future.

Table 4.10. Classification of boundary conditions according to benchmarking

No.	Mark	Classification	Comment
1	4	Sustainable	WSS is sustainable. It means that SIV meet the demand at the time of evaluation and the potential water sources is guarantee for extend plan of WSS in the future.
2	3÷4	Good	Water sources is not enough for water demand, but not too much. The problem could be solved through small improvement plan such as optimizing distribution network, reduction of water losses, and so on.
3	2÷3	Approaching water scarcity	The level of water scarcity is quite big. Thus, a big improvement plan is proposed such as looking for new supply sources to supplement for current sources, rehabilitation of physical asset of WSS, reduction of water losses.
4	1÷2	Water scarcity	The level of water scarcity is very serious. A comprehensive improvement plan of WSS need to take into consideration instantly.

If WSS has mark in value between 3 and 4, it means that water sources is not enough for water demand, but not too much. The problem could be solved through small improvement plan such as optimizing distribution network, reduction of water losses. However, if WSS with the mark is less 3, the level of water scarcity will be really a big problem. Thus, a big improvement plan of WSS is needed to take into consideration instantly.

4.3.2 The performance of total system

The system performance will be considered in aspects comprising efficiency of using physical asset, the coverage of water supply service, water supply time of service, and water losses management. The benchmarking is proposed for these indicators based on author's experience during the time of working on site with WSS and Distribution System and Facilities Design Standard number TC33/2006 of Ministry of Construction.

Table 4.11. The benchmarking of performance of total system

No.	PIs / Mark	4	3	2	1	Weight
2.1	**Efficiency of using physical asset (subgroup 1: PSe)**					**3**
PS_1	Pipes in use (%)	100%	100÷90%	90÷70%	<70%	2
PS_2	Coverage of WDN (%)	100%	100÷90%	90÷70%	<70%	3
PS_3	Volume of public tanks in use (%)	100%	100÷90%	90÷70%	<70%	2

No.	PIs / Mark	4	3	2	1	Weight
PS_4	Water storage capacity of public tanks in use (days)	>3	3÷2	2÷1	<1	1
PS_5	The number of valves in use (%)	100%	100÷90%	90÷70%	<70%	1
PS_6	The number of other devices in use (%)	100%	100÷90%	90÷70%	<70%	1
2.2	**The coverage of water supply service (subgroup 2: PSc)**					**3**
PS_7	The rate of households connected with WDN per total households (%)	100%	100÷90%	90÷70%	<70%	3
PS_8	Rate between households using 100% water from WSS and households connecting with WSS (%)	100%	100÷70%	70÷50%	<50%	3
2.3	**Water supply time of service (subgroup 3: PSt)**					**1**
PS_9	Average operation time of water supply service per day (hour/day)	24h	24÷20h	20÷10h	<10h	1
2.4	**Water loss and its components (subgroup 4: PSwl)**					**3**
PS_{10}	The rate between Non-Revenue Water and SIV (%) (%)	<10%	10÷25%	25÷40%	>40%	3
PS_{11}	Infrastructure leakage index: ILI (-)	<4	4÷8	8÷16	>16	3
PS_{12}	Apparent loss index: ALI (-)	<2	2÷4	4÷6	>6	3

The benchmark of system performance will be broken into four subgroups including efficiency of using physical asset (subgroup 1 – PSe), coverage of water supply service (subgroup 2 – PSc), water supply time of service (subgroup 3 – PSt), and water loss and its components (subgroup 4 – PSwl). The benchmark will be proposed to evaluate regarding to each group.

First – subgroup 1: Normally, all physical asset of WSS has to be in use. However, in fact, many parts of WSS do not work due to different causes during operation time, which leads to extreme influences on water supply capacity of system and waste of facility. In developing countries, physical asset is often deteriorated rapidly during running time due to the lack of fund for rehabilitation and a good management plan. The benchmarking will classify the level of using physical asset in four levels from 1 to 4 equivalent to (100%), (100÷90%), (90÷70%), and (<70%) of facility in use. The weight of indicators is arranged in priority order including PS_2 (weight 3), PS_1 and PS_3 (weight 2), PS_4, PS_5 and PS_6 (weight 1) depending on influence and coverage level of indicators. The average mark of this subgroup will be defined in Equation 4.3.

Average mark of subgroup 1 (PSe) = $\frac{2PS_1+3PS_2+2PS_3+PS_4+PS_5+PS_6}{10}$ (Equation 4.3)

The performance of using physical asset will be evaluated in 4 levels including good, acceptable, bad, and very bad. The physical asset of WSS in good level means that 100% physical asset are in use and do not need any activities to improve them. However, if it is in other levels such as acceptable, bad, and very bad, a plan of rehabilitation is necessary for WSS to repair or replace damage parts.

Table 4.12. The classification of subgroup 1 – efficiency of using physical asset

No.	Mark	Classification	Comment
1	4	Excellent	The performance of using physical asset is very good. It means that 100% physical asset of WSS are in use. There is not any waste of using physical asset.
2	3÷4	Good	Some parts of physical asset are not in use, but not too much. A plan of small repair should be carried out to find out damage parts and repair/replace.
3	2÷3	Poor	Many part of physical asset are not in use. Whole physical asset of WSS should check comprehensively to support for a plan of big rehabilitation.
4	1÷2	Very bad	Physical asset of WSS is deteriorated extremely. A plan of rehabilitation need to be implemented as soon as possible.

Second – subgroup 2: Similarly to the physical asset, the benchmarking for the coverage of water supply service (PS_7) is also broken into four levels corresponding to the percentage of service coverage 100%, 100÷90%, 90÷70%, and <70%. Customers can use some water sources at the same time to guarantee enough water over years. The less the number of customers use additional water sources, the higher the service quality is. Therefore, the benchmarking of indicator PS_8 will include four levels corresponding to the rate between households using many water sources and total households connecting with WDN (0%, 0÷10%, 10÷30%, and >30%). The coverage of water supply service is one of important indicators that reflect the performance of WSS. Thus, two indicators of this subgroup (PS_7 and PS_8) proposed the weight are 3 for both of them comparing with other indicators in group of performance system. The average mark of subgroup 2 (PSc) – the coverage of water supply service will be calculated in equation 4.4.

$$\text{The average mark of subgroup 2 (PSc)} = \frac{PS_7 + PS_8}{2} \quad \text{(Equation 4.4)}$$

The subgroup 2 – coverage of water supply service is also assessed in four levels comprising good, acceptable, bad, and very bad. If 100% water users in service area use water from WSS and they do not need to use any additional sources (WSS meet the water demand of all residents in service area), the coverage of water supply service will be classified in good level. However, if WSS does not cover all residents in service area and water users have to use many different water sources to have enough water over year, WSS will be classified in acceptable, bad or very bad levels depending on different coverages of water supply service (see Table 4.13).

Table 4.13. Classification of subgroup 2 – coverage of water supply service

No.	Mark	Classification	Comment
1	4	Excellent	It means that water supply service covers completely customers in service area and water from WSS is enough for all customers.
2	3÷4	Good	At least 90% customers use water from WSS, some of them have to use additional sources to have enough water during the time of water scarcity.
3	2÷3	Poor	At least 70% customers use water from WSS and many of them have to use additional sources to have enough water during the time of water scarcity.
4	1÷2	Very bad	Less 70% customers use water from WSS and most of them have to use additional sources to have enough water during the time of water scarcity.

Third – subgroup 3: Water supply time of service is 24/24 with continuous supply system. Yet, this indicator is often less 24 hours in developing countries because of many limitations that mentioned in chapter 1, 2, and 3. The longer the time of supplying water is, the higher the quality of service is. Thus, the benchmarking of this indicator (PS_9) will evaluate the quality of service in according to the number of hours supplying water of service. For instance, the benchmark includes four levels 24h, 24÷20h, 20÷10h, >10h corresponding to the mark levels from 4 to 1. The weight of this indicator (PS_9) proposed is 3 because this indicator is in behalf of the continuity of service. The water supply time of service is also evaluated in four levels including good, acceptable, bad and very bad corresponding different marks (4, 4÷3, 3÷2, and 2÷1). If supply source is always available (24/24) for customers, WSS will be classified in good level in supply time. Similarly, other levels such as acceptable, bad, and very bad will be equivalent to the remaining marks (4÷3, 3÷2, and 2÷1).

Finally – subgroup 4: Water loss is one of the most important indicators that reflects the operation and management performance of WSS. However, water loss can never be completely eliminated in WSS because it exists in large range of water distribution network. Thus, it always exists an unavoidable water loss in WSS and the target of all water utilities is to minimize water loss to reach this value. Based on AWWA (2012) and World Bank (2006), the benchmarking of non-revenue water (PS_{10}) is evaluated in four levels corresponding to its value such as <10%, 10÷25%, 25÷40%, and >40%. Infrastructure leakage index (PS_{11}) reflects the gap between current real water losses and unavoidable water losses, which shows potentiality of reducing real water losses of system. Hence, this indicator will be evaluated in four levels (4, 3, 2, and 1) corresponding to values of PS_{11} (<4, 4÷8, 8÷16, and >16) relied on Liemberger (2005). Similarly, the benchmark of PS_{12} (apparent loss index ALI) is also evaluated in four levels (4, 3, 2, and 1) corresponding to values of PS_{12} (<2, 2÷4, 4÷6, and >6) based on Mutikanga (2010).

So as to evaluate and classify the performance of subgroup 4 – water loss and its components, the weight of each indicator is proposed depending on important and influent level on the system. Namely, the total weight of subgroup 4 is 3 and distributed for PS_{10} 1, PS_{11} 1, and PS_{12} 1. The average mark of this subgroup (PSwl) – water loss and its components will be calculated in equation 4.5.

$$\text{The average mark of subgroup 4 (PSwl)} = \frac{PS_{10}+PS_{11}+PS_{12}}{3} \quad \text{(Equation 4.5)}$$

The performance of minimizing non-revenue water will be categorized in four levels including excellent, good, poor, and very bad.

Table 4.14. Classification of subgroup 4 – water loss and its components

No.	Mark	Classification	Comment
1	4	Excellent	Further reduction may be uneconomical unless if the cost of water is very high
2	3÷4	Good	There is room for improvement
3	2÷3	Poor	High revenue losses, acceptable where cost of water is very low
4	1÷2	Very bad	Very inefficient with poor meter management practices and in adequate policies for revenue protection. Urgent action required to minimize revenue losses

In order to evaluate the performance of total system, each subgroup will adapt with a weight depending on its important level. Namely, the subgroups are proposed with weights in the following: the subgroup 1 (PSe) – efficiency of using physical asset proposed weight 3, the subgroup 2 (PSc) – coverage of water supply service proposed weight 3, the subgroup 3 (PSt) – water supply time of service proposed weight 1, and the subgroup 4 (PSwl) – water loss and its components proposed weight 3. Then, the average performance of total system will be calculated in equation 4.6.

$$\text{The average performance of total system} = \frac{3xPSe+3xPSc+1xPSt+3xPSwl}{10} \quad \text{(Equation 4.6)}$$

Table 4.15. The performance of total system in different classifications

No.	**Mark**	**Classification**	**Comment**
1	4	Excellent	WSS is operated and managed very well. It means that 100% of physical asset are in use, WSS covers completely customers in service area, water is supplied 24/24, and non-revenue water is small amount of SIV (less 10%).
2	3÷4	Good	Some parts of WSS not in use (less 10%), the coverage of water supply service at least 90% water users in service area, and non-revenue water less 20% of SIV. A plan of small

No.	Mark	Classification	Comment
			repair should be carried out to improve the system performance
3	2÷3	Poor	Many parts of WSS not in use (less 20%), the coverage of water supply service at least 70% water users in service area, and non-revenue water less 30% of SIV. Whole physical asset of WSS should check comprehensively to support for a plan of big rehabilitation.
4	1÷2	Very bad	Physical asset of WSS deteriorated extremely, the coverage of water supply service less 70% water users in service area, and non-revenue water more 30% of SIV. A plan of rehabilitation need to be implemented as soon as possible.

Then, the performance of total system will be evaluated in four levels consisting excellent, good, poor, and very bad. WSS is in excellent classification when 100% physical asset are in use, 100% water users in service area use 100% water from WSS, water is supplied 24/24, and non-revenue water is less 10% comparing with SIV. In this level, activities of repairs and improvements are not necessary. However, if WSS is in other classifications, the performance of total system will need to be improved depending on its classification.

4.3.3 The system performance impacting on individual customers

4.3.3.1 Inequality of distribution (subgroup: ICid)

In order to evaluate inequality levels of distribution among different zones, the benchmark of these indicators will be broken into five levels from 1 to 5 and scored for every zone. The higher the mark is, the more advantaged the zone is. The way to score is different depending on different indicators.

Table 4.16. Benchmarking of inequality indicators

No.	Formulation	5	4	3	2	1	Weight
IC_1	(IC_1 of zones)/(water supply time of service)x100 (%)	100÷90	90÷70	70÷50	50÷30	<30	3
IC_2	(IC_2 of zones)/(average IC_2 of system) x100 (%)	>200	200÷150	150÷80	80÷50	<50	3
IC_3	(IC_3 of zones)/(average IC_3 of system) x100 (%)	<50	50÷80	80÷150	150÷200	>200	3
IC_{41}	(IC_{41} of zones)/(average IC_{41} of system) x100 (%)	>200	200÷150	150÷80	80÷50	<50	0.5

No.	Formulation	5	4	3	2	1	Weight
IC_{42}	(IC_{42} of zones)/(average IC_{42} of system) x100 (%)	>200	200÷150	150÷80	80÷50	<50	0.5
IC_{51}	(IC_{51} of zones)/(average IC_{51} of system) x100 (%)	>200	200÷150	150÷80	80÷50	<50	0.5
IC_{52}	(IC_{52} of zones)/(average IC_{52} of system) x100 (%)	>200	200÷150	150÷80	80÷50	<50	0.5
IC_6	(IC_6 of zones)/(average IC_6 of system) x100 (%)	<50	50÷80	80÷150	150÷200	>200	0.5

The benchmark of indicator IC_1 – time of collecting water will be assessed based on the percentage between average time collecting water of zone and time supplying water of service. The mark of IC_1 will depend on this percentage. The mark will be scored from 5 to 1 corresponding to the percentage amplitudes 100÷90%, 90÷70%, 70÷50%, 50÷30%, and <30%. The benchmark of IC_2 – average water flow at different zones will be evaluated based on the rate of average water flow of zone and average water flow of system. The mark of IC_2 is also broken into five levels from 5 to 1 corresponding to the percentage amplitudes (>200, 200÷150, 150÷80, 80÷50, and <50). Similarly to indicator IC_2, the benchmark of indicators IC_{41}, IC_{42} (%households connecting with WSS and % households only using water from WSS), IC_{51}, and IC_{52} (consumption level recorded by meters and real consumption level) have the same rules of evaluation and percentage amplitudes. In contrast, the indicator IC_3 and IC_6 have an opposite trend of above-mentioned indicators. It means that the bigger the value of IC_3 and IC_6 is, the more disadvantaged it is. Thus, with these two indicators, the benchmark is divided into 5 levels equivalent to percentage amplitudes (<50%, 50÷80%, 80÷150%, 150÷200%, and >200%).

The indicators IC_1, IC_2, and IC_3 directly reflect the influence of IWS on customers in three aspects comprising time of collecting water, water flow, and air volume while other ones IC_4, IC_5, and IC_6 are in behalf of customers' solutions to adjust to water scarcity. Besides, three latter indicators are also dominated by other factors such as fund, position (easy to use other water sources), and occupation (only using water for living or small business) of water users. Thus, evaluating the influence level of these indicators on WSS and customers, IC_1, IC_2, and IC_3 are much more important than IC_4, IC_5, and IC_6. For these reasons, the weight of these indicators are proposed as follows: IC_1, IC_2, and IC_3 being proposed to be 3, and IC_{41}, IC_{42}, IC_{51}, IC_{52} and IC_6 being proposed to be 0.5.Then, the average mark of each zone will be calculated in the following equation:

$$\text{Average mark of zone} = \frac{3IC_1+3IC_2+3IC_3+0.5IC_{41}+0.5IC_{42}+0.5IC_{51}+0.5IC_{52}+0.5IC_6}{11.5} \quad (4.7)$$

The difference in average mark among zones shows inequality of distribution in WSS. The more different in mark among zones it is, the more inequitable it is among zones. Thus, the benchmark will classify the level of inequality based on the maximum difference among zones in average mark in four level including equality, low inequality, high inequality, and extreme inequality. Namely, the equality level of distribution will be assessed in equality classification if the maximum difference of zones is less 1 in average mark. If the mark is in other levels (1÷1.5, 1.5÷2, and >2), WSS will be put in equivalent classifications such as low inequality, high inequality, and extreme inequality (see Table 4.17).

Table 4.17. The inequality of distribution in different classifications

No.	Maximum difference among zones in mark	Mark	Classification	Comment
1	<1	4	Equality	It means that water and air volume is distributed quite evenly in pipeline network and there is not too much different among zones.
2	1÷1.5	3	Low inequality	The inequality of distribution is inevitable in IWS and the maximum difference among zones less 5 in mark can be acceptable. However, a plan of reducing inequality should be taken into consideration.
3	1.5÷2	2	High inequality	The inequality of distribution is bad. An improvement plan need to carry out soon.
4	>2	1	Extreme inequality	The inequality of distribution is extremely serious. An improvement plan need to carry out as soon as possible.

The inequality of distribution is inevitable in IWS. Water utilities should have a suitable improvement plan depending on different levels of inequality. For example, WSS in equality classification means that water is distributed quite evenly in pipeline network and there is not too much different among zones whilst an improvement plan should be taken into consideration as WSS in low inequality kind. If WSS is in categorize of high or extreme inequality, an improvement plan will be necessary for WSS as soon as possible.

4.3.3.2 Water quality (subgroup: ICwq)

The indicators of water quality (charts and tables) will provide a comprehensive picture of changing water quality from supply sources to customers' private tanks. However, to benchmark and classify this group, this process need to be simplified. The benchmark will be proposed to evaluate for each parameter, and then the benchmark of water quality will be calculated equal to average of all parameters. For example, to benchmark the spread of E. coli in pipeline network, the benchmark will compare average number of E.coli at all disadvantaged test points with number of E.coli at supply source corresponding to two times: as soon as water coming to test points and once the running time of service (IC_7 and IC_8). The advantaged test points include points located at end or/and far or/and local high/low or/and high points of pipeline network. Moreover, to benchmark impact of private tanks on water quality, the benchmark also compare average number of E. coli after and before private tanks equivalent to two times: as soon as water coming to private tanks and once at the running time of service (IC_9 and IC_{10}).

Table 4.18. Benchmarking of water quality

No.	Formulation	5	4	3	2	1	Weight
IC_7	(average IC_7 of parameter at disadvantage test points)/(parameter at supply source) (time)	<1.5	1.5÷2	2÷3	3÷5	>5	3
IC_8	(average IC_8 of parameter at disadvantage test points)/(parameter at supply source) (time)	<1.5	1.5÷2	2÷3	3÷5	>5	3
IC_9	(average IC_9 of parameter after private tanks)/(average IC_9 of parameter before private tank) (time)	<1.5	1.5÷2	2÷3	3÷5	>5	1
IC_{10}	(average IC_{10} of parameter after private tank)/(average IC_{10} of parameter before private tank) (time)	<1.5	1.5÷2	2÷3	3÷5	>5	1

In order to classify the impact levels of IWS and private tank on water quality, the benchmark of each parameter will be divided into 5 levels from 1 to 5 corresponding to marks (<1.5, 1.5÷2, 2÷3, 3÷5, and >5). The higher the mark is, the less the impact of IWS and private tank are. The influence of IWS on water quality is much important than private tanks in water quality because the former influences in large range and much more difficulty to solve. Thus, the weight of indicators IC_7 and IC_8 is proposed to be 3 while the weight of IC_9 and IC_{10} is 1. Then, the average benchmark of each parameter and the benchmark of changing water quality in pipeline network will be calculated follow equation 4.7 and equation 4.8.

The average benchmark of each parameter = $\frac{3IC_7+3IC_8+IC_9+IC_{10}}{8}$ (Equation 4.8)

The benchmark of water quality = average (parameter 1, parameter 2…) (Equation 4.9)

Thanks to the mark levels, the change of water quality from supply source to customers' private tanks can be classified in four levels including no impact, low impact, high impact, and extreme impact corresponding to four mark levels (<2, 2÷3, 3÷5, >5). Depending on the different classifications, water quality is also influenced by surroundings in different levels. The leakages of pipeline network can be estimated from test points where water quality is reduced rapidly. A plan of replace and repair should be taken into consideration contingent on classifications.

Table 4.19. The impact of IWS and private tank on water quality in different classifications

No.	Value of PIs	Mark	Classification	Comment
1	Value PIs of all parameters <2	4	No impact	The quality of pipeline network is good. This means that there are not many leakages in the network. IWS and private tanks do not influence so much on water quality.
2	(value PI of one parameter in all) 2÷3	3	Low impact	Water quality is influenced by surroundings, but in acceptable level. It proofs that there are some leakages in pipeline network. An improvement or replace plan should take into consideration.
3	(value PI of one parameter in all) 3÷5	2	High impact	Water quality is influenced seriously by surroundings. The leakages of pipeline network can be estimated from test points where water quality is reduced rapidly. A plan of replace and repair needs to be implemented as soon as possible.
4	(value PI of one parameter in all) >5	1	Extreme impact	Water quality is influenced very seriously by surroundings. The leakages of pipeline network can be estimated from test points where water quality is reduced rapidly. A plan of replace and repair needs to be implemented immediately.

Besides, all parameters of water quality at test points should also compare with national technical regulation on domestic water quality QCVN 02: 2009/BYT. This comparison is important to know water quality of WSS in national standard and an improvement plan of water quality if necessary.

4.4 Data variables and methods to collect

In order to calculate indicators, the data variables have to be collected in the first step. Based on the indicator system proposed in section 4.2, the data variables can be broken into some groups in the following:

Table 4.20. Data variables

No.	Group	Data variables
1	Water and air volume	Water system input volume (SIV) in dry season and one year, potentiality of water sources, water loss and its components, water demand, water consumption, water flow, air volume
2	Physical asset of WSS	Map data, supply sources (e.g. pump station), water treatment plan, reservoir, distribution network, public tanks, hydrant, valve, tap, control and management devices, and others on WSS.
3	Physical asset of water users interacting with WSS	Water meter, close valve (before or after water meter), private tank, and float valve installed in private tank.
4	Data for analysing inequality of distribution and the change of water quality in WSS	- Air volume, water volume, time of collecting water at different points in WSS - Water quality of water samples at different points in WSS
5	Operation data	Operation diary of Water Undertaking (supply time of service), data of repair and replace, and so on
6	Customer information	Population, households

In Vietnam, installing water meter is compulsory requirement for all water users from WSS and the indicator of customer meters is recorded by staffs of Water Undertakings monthly (pursuant to decree No.117/2007/NĐ-CP of Vietnamese government, http://vanban.chinhphu.vn). Thus, data of water consumption are available in every WSS in Vietnam. However, the remaining data are often not available or insufficient in S-IWS. To provide a general method system of collecting data variables, the research will introduce particular methods to collect all missing data.

In S-IWS, observation and control devices such as instruments to record water input volume of WSS, pressure control valve, air valve are hardly installed in WSS. Besides, there are not any state-of-the-art devices (e.g. leakage detector) supporting for evaluation process. The common hydraulic module such as EPANET is even impossible to apply for S-IWS by dint of intermittent supply. However, labor costs are often not very expensive in these areas. Moreover, the evaluation process would be supported from Water Undertakings. Thus, the methods proposed have to take these pros and cons into consideration. There are some rules in all proposed methods including intelligibility (easy to understand), simplicity (simply to apply), low cost, and maximum using available devices and facility from Water Undertakings and local area. Based on the above-mentioned missing data and rules, there are some methods proposed to collect missing data in the following:

4.4.1 Field investigation to collect data of physical asset of WSS

In order to collect data of physical asset, a field investigation along with pipeline network is required. The target of this investigation is to collect sufficient data of physical asset of water distribution system from supply source to connection points of customers. This method requires some tools including a handheld Global Positioning System (GPS), computer, camera, notebook and pen. The investigator will go along with the pipeline network to mark specific points of pipes (e.g. bend, branch, change of direction, pipe diameter, material, location, and so on) and take note important information during field investigation such as leakages in pipes (if possible). Equally important, the investigators can also collect sufficient data about physical asset of WSS during field survey comprising supply source, water treatment plant, reservoir, tank, valve, hydrant, tap, and related data. The collected data would include in some formats such as electronic data (e.g. coordinates points, route), take notes, videos, pictures, diagram, charts, and so on. It is the best way if the field investigation is carried out by operation staffs of Water Undertakings or the investigators can go with operation staffs of Water Undertakings during the survey because the operation staffs are the most understand people about WSS.

The data from field investigation will enter into computer. Based on electronic data from GPS device, the map of distribution system can be drawn by using some software such as ArcMap or AutoCAD. Besides, to enhance the accuracy, the map should be compared and corrected with Google map and operation staffs' experience.

These data are not only necessary for calculating indicators of physical asset, but they are also mostly used for identifying other indicators such as the coverage of service, boundary condition.

Table 4.21. The data extracted from investigation along with WSS

No.	Kind of data	Format	Expectation data
1	Coordinates of specific points of pipeline network	Electronic data	Map of distribution network
2	Coordinates of structure, device, important positions in WSS	Electronic data	Coordinates of supply source, pump station, reservoir, tank, valve, hydrant, tap, leakages, and related others on the map of distribution system
3	Properties of physical asset	Take notes	- Pipe: Diameter, material, length, position (ground, underground), quality, leakages (If possible), year of installing, status - Reservoir/tank: size, material, quality, position, leakages (if possible), year of construction, status - Pump station: Origin, type, year of operating, status, and technical information of pump - Water treatment plant (if have): Water input and output volume per day, water quality, status - Valve, hydrant, tap, and others: origin, type, year of installing, quality, status
4	Pictures and video	Electronic data	Picture/video of supply source, reservoir, water treatment plant, tank, valve, hydrant, tap, leakages, special positions, related others

It supposes that all devices using for field investigation are not available. The cost of survey is estimated including handheld GPS (about 500 EUR), computer (500 EUR), and stationary (20 EUR). Thus, total cost of devices for field investigation about 1000 EUR. The time spending for field investigation will depend on the scale of WSS.

4.4.2 House-to-house investigation to collect customer information

So as to collect the data related to customer, a house-to-house investigation is required. The target of house-to-house investigation is to collect physical asset of water users interacting with WSS including water meter (origin, type, year of installing, running status), private tank (position, size, material, year of installing, running status), float valve (origin, type, year of installing, running status) as well as data related to water demand of water user such as number of people, occupation, type of water source used, and etcetera. Besides, GPS will be used to mark coordinates of water users. The first step of this method requires to design a questionnaire using for interview process. The questionnaire is designed based on kind of requirement data and author's field experience working with WSS.

In general, the data collected from house-to-house investigation could be broken into 4 types. The first type is coordinates of water users on the map of water distribution system. Thanks to the data, positions of water users from different sources (only from WSS, both WSS and other sources, or only from other sources) will be defined on the map. It is very necessary for improvement and extension plan of WSS as well as operation and management activities. The second type will provide sufficient data about physical asset interacting with WSS such as meter, private tank, and float valve, which is indispensable for analysing water quality, inequality of distribution, water demand, water losses, and so on. The third type will provide data related to water demand such as population, household, target and cost of using water, customer complaints, and etcetera. Finally, the last type will give pictures and videos related to water users such as private tank, water meter.

Table 4.22. Kind of data extracted from questionnaires

No.	Kind of data	Format	Expectation data
1	Coordinates of water users	Electronic data	Identify positions of water users on map in different groups - Group 1: Only using water from WSS - Group 2: Using water both from WSS and other sources - Group 3: Only using water from other sources
2	Physical asset of water users interacting with WSS	Word or excel	- Private tank: Location (cistern, ground, or roof), size, material (e.g. concrete, bricks, stainless steel), times of cleaning per year, year of building, and status - Water meter and float valve: origin, type, year of installing, status
3	Information related to water demand	Word or excel	- Population, household, occupation, cost of using water per year, target of using water - Complaints of customers about quality of service
4	Pictures and video	Electronic data	Picture and videos related to water users such as private tank, water meter, and so on

4.4.3 The method of observing customer meters

In Vietnam, 100% water users have to install water meters when they connect WSS (pursuant to decree No.117/2007/NĐ-CP of Vietnamese government, http://vanban.chinhphu.vn). Thanks to this, observing and recording data of customer meters can be implemented at all points in WSS, which is very important for analysing inequality of distribution and calculating air volume. Each connection includes close valve, meter, and fittings in order (see Figure 4.3).

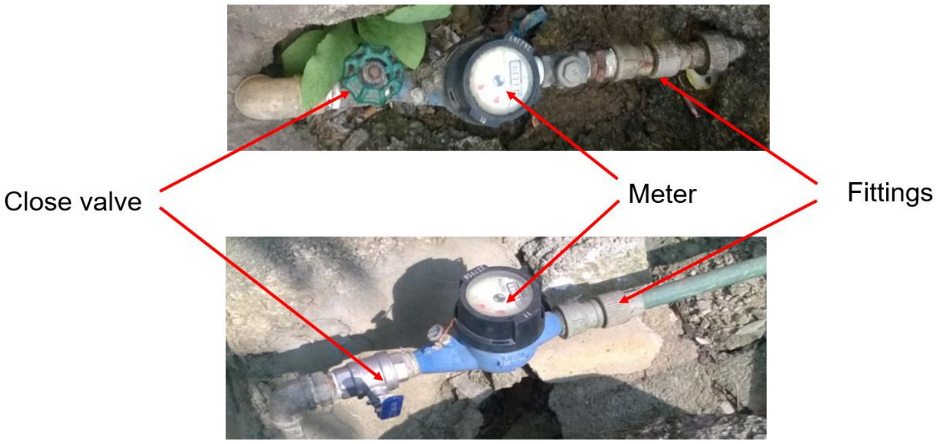


Figure 4.3. Devices at every connection

The target of this method to collect data about time water coming to customers, water flow and air volume at different positions in distribution network, which is necessary for calculating indicators of inequality of distribution and apparent loss due to air volume. The method of observing customer meters includes some steps in the following:

Selecting test locations: To assess inequality of distribution in pipeline network, chosen positions have to cover all advantaged positions (near supply sources and/or low positions), medium positions (middle WPN), and disadvantaged positions (far and/or high positions from supply sources) points.

Test setup: An experiment is carried out on site by observing private meters at chosen positions to define such variables in the following:

- Mark specific positions of water consumption on the map including advantaged, medium and disadvantaged points (highest and lowest points, far and near water resource, etc.).
- Check water meters and private tanks of buildings to make sure that these tanks are empty enough to store the water before supplying water of service.
- Record data at these positions comprising: Start time of providing water of service, time when meter start running, time when water coming, time of stopping for collecting water, and indicators of water meters relevant to those times.
- Calculate parameters: Duration of airflow and volume of air, duration of water flow and volume of collected water of households at positions.

Table 4.23. Data recorded from field experiment

Position	Time when			Indicator of meter when		
	Meter running (airflow come)	Meter running (water flow come)	Stop collecting water	Meter running (airflow come)	Meter running (water flow come)	Stop collecting water
1	T_{11}	T_{12}	T_{13}	I_{11}	I_{12}	I_{13}
2	T_{21}	T_{22}	T_{23}	I_{21}	I_{22}	I_{23}
…	…	…	…	…	…	…
i	T_{i1}	T_{i2}	T_{i3}	I_{i1}	I_{i2}	I_{i3}
…	…	…	…	…	…	…
n	T_{n1}	T_{n2}	T_{n3}	I_{n1}	I_{n2}	I_{n3}

It is noted that the water running through the pipe network and the airflow ahead of the arrival of the water happens always at the beginning of the network filling process. This process can be divided into 3 periods: airflow, a combination flow of air and water, and water flow when water fulfills pipe. Meters could not recognize the difference between air and water; thus, they will measure all those volume, which triggers their inaccurate measure.

Calculating the air volume in the time of combination of air and water flow is very complex because it is contingent on movable variables such as time of pile full water, volume percentage of water and air follow time from water coming to water full pipe. However, the diameter of the house connection pipes is mostly quite small (about 20mm); thus, the time of water and air flow is quite short, which leads to air volume is quite small in this period. For this reason, such volume is ignored in this research.

The data extracted from Table 4.23 can be used to calculate some important parameters as follows:

4.4.3.1 Calculating apparent loss due to air volume

Air volume at one test point is calculated by equation 4.11:

$$V_{air\text{-}i} = I_{i2} - I_{i1} \qquad \text{(Equation 4.10)}$$

Where:

$V_{air\text{-}i}$ (m^3): Air volume at test point i

I_{i1} (m^3): Indicator of water meter at test point i when air flow coming

I_{i2} (m^3): Indicator of water meter at test point i when water flow coming

Total air volume of pipeline network in one day is calculated by equation 4.12:

$$V_{\text{air-network}}^{1day} = \sum_{i=1}^{n} \frac{(V_i + V_{i+1})N_{\text{connection}}}{2} \qquad \text{(Equation 4.11)}$$

Where:

$V^{1day}_{air\text{-}network}$ (m^3) : Total air volume of pipeline network in one day

V_i (m^3) : Air volume at test point i

V_{i+1} (m^3) : Air volume at test point i+1

$N_{connection}$ (-) : Number of connection between test point i and test point i+1

n (-) : Total number of test points

Total air volume of pipeline network in one day has to be smaller than total vacuum volume inside pipeline network.

$$V^{1day}_{air\text{-}network} \leq \sum V_{(inside)pipe} \qquad \text{(Equation 4.12)}$$

Where:

$\sum V_{(inside)pipe}$ (m^3): Total vacuum volume inside pipeline network

Total vacuum volume inside pipeline network can be calculated easily from data of physical asset of pipeline network (length and diameter of pipes).

Finally, total air volume of pipeline network in one year is calculated by equation 4.14.

$$V^{1year}_{air\text{-}network} = \text{(total number of days supplying water in one year) x } V^{1day}_{air\text{-}network} \quad \text{(Equation 4.13)}$$

4.4.3.2 Data for analysing inequality of distribution

The time of air and water coming to customer meter can be calculated as follows:

$$T_{air\text{-}i} = T_{i1} - T \text{ and } T_{water\text{-}i} = T_{i2} - T \qquad \text{(Equation 4.14)}$$

Where:

$T_{air\text{-}i}$ (hh:mm:ss): Time duration air flow coming to customer meter i

$T_{water\text{-}i}$ (hh:mm:ss): Time duration water flow coming to customer meter i

T (hh:mm:ss): Starting time of supplying water at supply source

T_{i1} (hh:mm:ss): Time when air flow coming to customer meter i

T_{i2} (hh:mm:ss): Time when water flow coming to customer meter i

This data will be used to estimate time of air and water distributed to customers at the beginning of network fulfil process. Besides, number of customers collecting water in time can be defined thanks to the combination of this data and customer data.

Similarly, air volume forced to receive at each test point is also calculated in equation 4.11 while water flow at each test point will be calculated in the following equation:

$$Q_i = \frac{I_{i3} - I_{i2}}{T_{i3} - T_{i2}} \quad \text{(Equation 4.15)}$$

Where:

Q_i (m^3/s) : Water flow at test point i

I_{i2} (m^3) : Indicator of water meter at test point i when water flow coming

I_{i3} (m^3) : Indicator of water meter at test point i when stop collecting water

The difference of air and water volume at different points will provide a comprehensive picture about inequality of distributing air and water in WSS.

4.4.3.3 Using this method to calculate apparent loss due to meter inaccuracy

The idea of this method is to compare the water volume measured by meters with net water volume. It means that water volume flowing through meter will be stored in a net tank which can calculate exactly volume of water inside it. The net tank would be a private tank or a mobile tank as long as the volume of this tank can be defined exactly.

In WSS, there are a huge number of meters; thus, checking all meters is impossible. For this reason, selecting a meter group that represent for all meters in WSS is necessary. Afterwards, the meter accuracy of whole system will be estimated based on the result of testing this presentative group. There are two important factors that influence on the accuracy of meter including origin and age in Vietnam. The older meters are, the more inaccurate they are. Besides, meters manufactured by developed countries such as America or Germany often have a much higher accuracy comparing with meters from developing ones (e.g. China). The process of measuring the accuracy of meter will involve in some steps in the following:

- Arrange whole meters in 2 types meter age and meter brand. Data of meters can be collected thanks to checking all contracts between Water Undertaking and customers or data from house-to-house investigation.
- Choose some meters from each type to check the accuracy on-site.
- Implement experiment on site including some steps such as picking out households having water meters matching selected ones, recording indicator of water meter of these household before and after collecting water, recording water levels of private tanks before and after collecting water, and making sure that all households will not consume water during experiment.
- Based on these data, calculate two parameters: Volume of collected water from the change of indicator of meter and volume of water from the change of water levels in net tank.
- Inaccurate volume of meter = (Volume of water follow meter) - (Volume of real water flowing into the net tank).

- Inaccurate water volume of whole meters in WSS in one year will be estimated regarding to the group of representative meters.

4.4.3.4 Using this method to calculate apparent loss due to float valve

Float valves are installed inside private tanks to automatically stop collecting water when the tanks are full. According to position, the private tank can be divided into three classification: cistern, ground, and roof tank. A customer's house would have one, two, or all three of them depending on many factors such as water demand, position in distribution network, and finance. Not all float valves influence on meter inaccuracy. The float valve installed inside tank can impact on the accuracy of meter or not contingent on the combination between position of tanks in house and float valve. For example, if a house have both cistern tank (no float valve) and roof tank (have float valve) and water from WSS flow directly into cistern tank and then is pumped up to roof tank by private pump, the float valve installed at roof tank will do not influence on the accuracy of water meter.

Therefore, the types of combining between tank position and float valve impact on the accuracy of water meter need to identify in the first step. The Table 4.24 will introduce the combination types between private tanks and float valves commonly in Vietnam and analyse the kind of combinations impact on the accuracy of water meter.

Table 4.24. Type of combination between private tank and float valves

No.	Type of combination	Analyzing the influence of float valve on meter accuracy	Yes or No
1	Building having roof tank installed float valve	Float valve impacts on meter in 2 periods: - From roof tank nearly full to full - Water users consume water in the period of roof tank nearly full or full	Yes
2	Building having roof tank without float valve	No float valve	No
3	Building having ground/cistern tank installed float valve	Float valve impacts on meter in 2 periods: - From ground/cistern tank nearly full to full - Water users consume water in the period of ground/cistern tank nearly full or full	Yes
4	Building having ground/cistern tank without float valve	No float valve	No
5	Building having both roof tank and ground/cistern tank, but only roof tank installed float valve	Water is collected and stored at ground/cistern tank before pumping into roof tank by private pump. The float valve inside roof tank plays the role to prevent water spilled in the duration of pumping water from ground/cistern tank to roof tank, therefore, it does not involve in water supply process of WDN	No
6	Building having both roof tank and ground/cistern tank, but only ground/cistern tank installed float valve	Float valve impacts on meter in 2 periods: - From ground/cistern tank nearly full to full - Pumping water from ground/cistern tank to roof tank in the duration of ground/cistern tank nearly full of full	Yes

No.	Type of combination	Analyzing the influence of float valve on meter accuracy	Yes or No
7	Building having both roof tank and ground/cistern tank without float valve	No float valve	No
8	Building having both roof tank and ground/cistern tank installed float valve	Float valve impacts on meter in 2 periods: - From ground/cistern tank nearly full to full - Pumping water from ground/cistern tank to roof tank in the duration of ground/cistern tank nearly full of full	Yes

Combination types can be impacted by the presence of float valves to be (1), (3), (6) and (8). Thanks to data from house-to-house investigation and above-mentioned combinations, the percentage of houses that can impact negatively on the accuracy of water meters will be defined.

In the next step, the impact level of float valve on the accuracy of water meters during the time of water level in private tank from nearly full to full need to be calculated. Similarly to on-site experiment to identify the accuracy of meters themselves in section 4.4.3.3, checking the impact of float valves on meters are also implemented for a representative group follow age and origin of float valve. Afterwards, the impact of float valves on whole system will be estimated based on the result of testing this presentative group. The process will involve in some steps in the following:

- Arrange whole float valves in 2 types: age and origin. Data of float valves are collected thanks to house-to-house investigation.
- Choose some float valves from each type to check the impact.
- Implement experiment on site including some steps such as picking out households having float valves matching selected ones, recording indicator of water meter of these household from private tank nearly full to full, recording water levels of private tanks from private tank nearly full to full, and making sure that all households will not consume water during experiment.
- Based on these data, calculate two parameters: Volume of collected water from the change of indicator of meter and volume of water from the change of water levels in private tank.
- Apparent loss due to float valves = (Volume of water follow meter) - (Volume of real water flowing into the net tank).
- Apparent loss due to float valves of whole system in one year will be estimated regarding to the group of representative meters.

However, the impact of float valve on meter inaccuracy not only depends on the type of combination between private tank and float valve, but also is it contingent on water supply time of service, time of collecting water of household and water level inside private tank at time. For instance, time of consuming water of water user, the time of private tank nearly full or full, and water supply time of service have to be simultaneous, which causes a negative effect on measuring meter.

4.4.4 Methods to measure SIV, availability and potentiality of water sources

First, in order to measure water input volume (SIV) at supply sources, some measurement devices can be used such as UDM200. The measurement devices would be installed on pipes after supply sources to record SIV daily. If water of the system is treated by a water treatment devices/station/plant, SIV will be defined thanks to the capacity of water treatment devices/station/plant.

In a case of without any measurement devices, building a sharp-crested weir before or after supply source could be a good idea to measure water input volume. Then, water flow of water source will be calculated as water flow through triangle sharp-crested weir (see Figure 4.4). Construction of a sharp-crested weir is a simple and inexpensive method to identify SIV. Measuring SIV follow this method is carried out in some steps as follows:

- Build a triangle sharp-crested weir at water intake point of system before or after supply water source.
- Record upstream levels of weir in time. This data can be recorded hourly or some times in a day contingent on change of water level by operation staffs of Water Undertaking or by an automatic instrument.
- SIV is calculated like water flow pass a triangle sharp-crested weir.

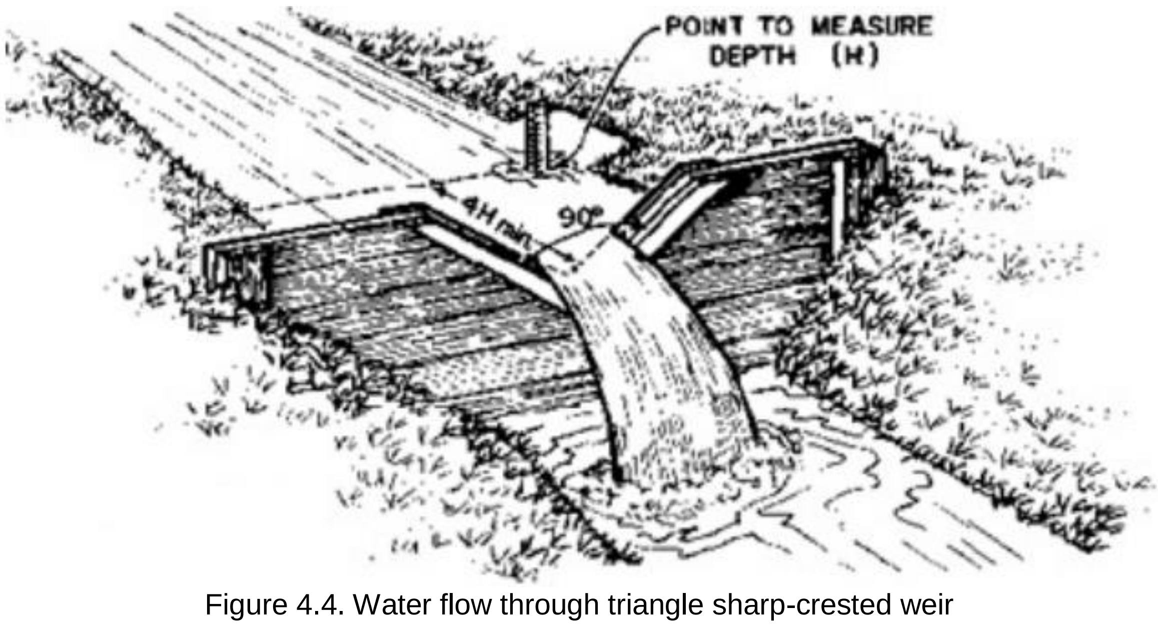


Figure 4.4. Water flow through triangle sharp-crested weir
(source: https://www.slideserve.com)

$Q = 4.427\ H^{2.5}$ (l/s) (Equation 4.16)

Where: H (dm) - The water depth from lowest point of triangle sharp-crested weir to water surface

This method is suitable with condition of S-IWS in Vietnam because of reasons: (1) Low cost of construction: The material for constructing a sharp-crested weir can be made up of bricks, concrete, stones which are very popular and cheap in Vietnam. The price of hiring employees for building is not very expensive (about from 7 to 15 EUR per person per day). Moreover, the construction does not need to use modern machines because of its simplicity. Thanks to these reasons, the construction cost is about from 2 to 10 million VND (from 80 to 400 EUR) depending on its location, materials and scale. (2) Non-cost of operation: There is always at least one staff for operation at water resource point. Therefore, Water Undertakings can require this staff for recording the change of water upstream levels daily. (3) Simple operation and construction: The construction of a triangle sharp-created weir is like constructing an element of channel that is not complex.

To enhance the accuracy of output data, the triangle sharp-crested weir and channel before and after the weir should be clean regularly.

Second, measuring capacity of potential sources will be proposed depending on kind of sources (e.g. surface or underground water). For example, if it is surface water such as river, lake, pond, or reservoir, we could use measurement data from department of meteorology in research area to estimate capacity of potential sources. Even if surface water is small runoff, building a sharp-created weir could be a good ideal to measure water flow. Besides, if it is underground water (e.g. water in Karst caves), capacity of potential source will mostly depend on capacity of water exploitation technology (e.g. water pump technology).

4.4.5 Methods to calculate water demand

The volume of water demand (WD) will be calculated pursuant to water supply standard of service area (Vietnamese Water Supply - Distribution System and Facilities Design Standard number TC33/2006 of Ministry of Construction). Namely, water demand includes water for households, business, governmental offices, and public services. WD is calculated in the following formulation:

$$WD\ (m^3/day) = WD_{dm} + WD_{ps} + WD_b + WD_L \qquad \text{(Equation 4.17)}$$

Where:

WD_{dm}: domestic water (m^3/day)

WD_{ps}: Water for public service (m^3/day)

WD_b: Water for business (m^3/day)

WD_L: Water loss in distribution system (m^3/day)

The volume of domestic water is calculated by standard water volume for one person in one day (wd) multiply by total population in service area (P).

$$WD_{dm}\ (m^3/day) = \frac{wd \text{ x } P}{1000} \qquad \text{(Equation 4.18)}$$

Where:

wd (liter/day/capita) : Standard water volume for one person in one day

P (people) : Total population in service area

Pursuant to Vietnamese Water Supply - Distribution System and Facilities Design Standard number TC33/2006 of Ministry of Construction, water volume for public services is calculated = 10% domestic water, water for business = 10% domestic water, and water loss in distribution system < 25%. Therefore, the parameters can be preliminarily calculated as follows:

$$WD_{ps} = 10\%\ WD_{dm}$$

$$WD_{b} = 10\%\ WD_{dm}$$

$$WD_{L} = 20\%\ WD_{dm}$$

4.4.6 Using water balance to calculate components of water losses

System input volume, water consumption, and water loss have an interacting relationship. In a WSS water system input volume is always equal to the total of water consumption and water loss. Based on water balance proposed by Alegre, et al., (2017), components of water loss will be identified (see Table 4.25). First, total water loss is equal to system input volume minus authorized consumption. Next, apparent loss due to air volume, inaccuracy of meter, and float valve will be calculated by method of observing customer meters (see section 0) while apparent loss due to unauthorized consumption (water theft) will be estimated based on data of house-to-house investigation. Namely, the volume of water theft can be estimated as follows:

Table 4.25. Steps to calculate components of water losses ((Alegre, et al., 2017)

<table>
<tr><td rowspan="8">System input volume (1)</td><td colspan="3">Authorized consumption (2)</td></tr>
<tr><td rowspan="7">Water loss (3)</td><td rowspan="4">Apparent loss (8)</td><td>Airflow at the beginning of supplying water (4)</td></tr>
<tr><td>Metering inaccuracies (5)</td></tr>
<tr><td>Private tank and float valve (6)</td></tr>
<tr><td>Unauthorized consumption (water theft) (7)</td></tr>
<tr><td rowspan="3">Real loss (9)</td><td>Leakage from storage tanks (10)</td></tr>
<tr><td>Leakage from transmission mains (11)</td></tr>
<tr><td>Leakage from distribution network (12)</td></tr>
</table>

Note: The number inside parentheses shows the order of calculating

- Estimate the number of households using water under-registration based on: Data from house-to-house investigation, the amount of water consumption follow meter of staffs of Water Undertakings or/and governmental staffs in service area, water usages consuming extraordinarily, and related data.

- Calculate water theft relied on the same households' water consumption about positions, the number of people, occupation, and others.
- Calculate PIs and assess the results

Afterwards, total apparent loss is equal to total of its components.

In the next step, total real loss is calculated equal to total water loss minus total apparent loss. The total water loss includes leakage from storage tanks, transmission mains and distribution network.

Leakage from storage tanks: In order to quantify leakage from storage tanks, Fallis, et al., (2011) presented a method of drop test (or volumetric test). In this method, the tank should first be filled to its maximum level, and then closing the inlet and outlet valves. Test period is suggested from 4 to 12 hours. The leaked water volume is calculated by comparing water volumes of tank at the beginning and at the end of test thanks to observing the fluctuations in the water level.

Leakage from transmission mains: Using portable flow meters (if bulk water meters are not available at the transmission mains) were proposed to quantify leakage from the transmission and/or distribution mains because transmission mains usually have only few branch connections (Fallis, et al., 2011). The flow rate will be measured simultaneously at the upstream and the downstream end of a pipe section. Steady flow conditions, fully filled pipes and that all lateral connections to the other network can be closed are compulsory requirements to assure a good result.

Finally, the leakage from distribution network will be calculated by total real loss minus leakage from storage tanks and transmission mains.

4.4.7 Methods to measure the change of water quality in WDN

In order on define the change of water quality from the supply source to private tank of water users, water quality needs to checked at many different positions in pipeline network as well as water samples before and after private tanks. To ensure a good result, the process of collecting data should comply with some rules as follows:

Selecting test locations: Chosen positions have to cover all advantaged positions (near supply sources and/or low positions), medium positions (middle WPN), and disadvantaged positions (far and/or high positions from supply sources), and specific points such as near local high/low points, near contaminated sources, leakages (if possible), and so on.

Choosing test parameters: As analysing in section 4.2.3.2, it will be the best way if all 14 parameters pursuant to national technical regulation on domestic water quality QCVN 02:2009/BYT are checked for evaluation process of water quality. However, in fact, selecting test parameters will depend on some factors such as budget, time, available devices and chemistry for test process. Some parameters such as total coliform and E. coli, turbidity should be prioritized to choose because they represent the spread of common underground contaminated sources (e.g. dirties, mud, bacteria). Besides, some WSS are put in special areas where can contain potential underground contaminated sources or industrial areas (e.g. arsenic, pesticides) which can go in pipeline network. Then, parameters related to the contaminated sources should be involved in test progress.

Water samples will be taken at 2 times during the time of supplying water: First time – as soon as water coming to customers and second time – during the time of supplying water. So as to take water samples at the first time, collectors need to wait at test points before time supplying water of service and water samples will be collected as soon as coming to test points. In the second time, it is not stressful about time of collecting water samples. Collectors can take water samples after some hours of time supplying water of services.

The preservation and analyse of water samples comply with Vietnamese standard of sampling and testing water quality TCVN6663-1:2011.

4.4.8 Method to collect other data

Some kinds of data related to evaluation process such as data of operation and management (diary of running pump station, pipe breaks, leakages, repair and replace pipe, valve, hydrant, and so on), contracts between customers and Water Undertakings, customer complaints, water thefts, and related data can be collected from Water Undertakings. In case, they are not available or insufficient, the evaluation can be evaluated preliminary for the first year based on available data. Afterwards, a process of data storage should be required for Water Undertakings to have enough data for evaluation in next year.

5 Application TPEs for case study - Dong Van city

5.1 Collecting data according to the proposed methods

Some data can collect from Water Utility in Dong Van and related others including: (1) water consumption from customer meters (from 2010 to 2016), diary of pump stations, and contracts between Water Utility and customers, standard of using water for drinking in study area. Analysing these data, there are some kinds of data can be extracted to use for the process of performance evaluation as follows:

Authorised consumption from 2010 to 2016: Water consumption recorded by operation staffs every month. Table 5.1 provides a brief picture of water consumption in Dong Van city in the period between 2010 and 2016, which is extracted from data provided Water Undertaking in Dong Van city (CERWASS). There are three kinds of water users including governmental office, business, and household.

Table 5.1. Water consumption follow customer meter 2010 – 4/2016 (m^3)

No.	Customer	2010	2011	2012	2013	2014	2015	4/2016
1	**Total water usage**	**134964**	**128089**	**110830**	**155255**	**159724**	**164016**	**50677**
2	**Average**	**11247**	**10674**	**11083**	**12938**	**13310**	**13668**	**12669**
	% office	33%	34%	23%	27%	28%	25%	23%
	% business	12%	1%	8%	5%	4%	6%	9%
	% household	55%	64%	69%	67%	68%	68%	69%
3	**Total customers installing meter**	**575**	**633**	**664**	**695**	**736**	**796**	**830**
3.1	Governmental offices	**60**	**69**	**61**	**67**	**68**	**69**	**69**
	Number of undertakings using water	**49**	**53**	**47**	**51**	**54**	**55**	**53**
	%	*82%*	*76%*	*77%*	*77%*	*80%*	*79%*	*77%*
3.2	Business	**47**	**30**	**32**	**34**	**37**	**43**	**49**
	Number of households using water	**41**	**23**	**22**	**21**	**18**	**20**	**25**
	%	*87%*	*77%*	*69%*	*61%*	*50%*	*46%*	*51%*
3.3	Households	**468**	**559**	**571**	**595**	**632**	**684**	**712**

No.	Customer	2010	2011	2012	2013	2014	2015	4/2016
	Number of households using water	**349**	**382**	**398**	**431**	**422**	**452**	**479**
	%	74%	68%	70%	72%	67%	66%	67%
4	**% Average using water**	**76%**	**72%**	**70%**	**72%**	**67%**	**66%**	**67%**

Time of supplying water of pump stations: Water supply time or service is extracted from operation diary of two pump stations Lang Nghien and To 5 from 2013 to 2016. The time of pumping water at pump stations witnesses an increase tendency. For example, water pumping time in average at Lang Nghien pump station is only 8 hours 53 minutes in 2013, but it significantly goes up in next years (2014 – 10hours 07 minutes, 2015 – 10hours 20 minutes, and 2016 – 12hours 09 minutes). However, this series of data are discrete and adequate.

Data of customer meters: All water meters have been installed for households in Dong Van city since 2003. They are made in of Indonesia, China, Thailand, and some other countries. Namely, most meters installed in Dong Van city origin from Indonesia with 727 ones while other kinds account for a small proportion. Besides, all meters made in of Indonesia have been installed since 2008 whilst other remaining meters are operated before 2009. Checking quality of meters is implemented every five years.

Table 5.2. Statistics of water meter follow age and origin

Year	Indonesia	China	Thailand	Others	Total
2003				5	5
2004		4			4
2005		7			7
2006		6			6
2007		5			5
2008	97				97
2009	81		30		111
2010	90				90
2011	76				76
2012	56				56
2013	74				74
2014	70				70
2015	141				141
2016	42				42
Total	**727**	**22**	**30**	**5**	**784**

Standard of using water for drinking in study area: Two standards are necessary for the process of performance evaluation including national technical regulation on domestic water quality QCVN 02:2009/BYT of Ministry of Health and Distribution System and Facilities Design Standard number TC33/2006 of Ministry of Construction.

Table 5.3. The missing data

Group	Missing data
Boundary conditions	System water input volume (SIV)
	Availability and potentiality of water sources
The performance of total system	Map of distribution network and devices (e.g. pump station, public tank, valve, tap, hydrant)
	Parameters of distribution network and devices: Length, diameter and material of pipes, pipes in use and in damage , data of public tanks (location, size, material and status), data of valves, tap, hydrant, meter (type, origin, status)
	Data of physical asset inside customers' buildings interacting with WDN: Customer meter (type, origin, status), private tank (location, size, material, status), float valve (type, origin, status)
	Population: Population and households where WDN reaches, population and households in evaluated area, the rate of population growth
	Customer: Population and households only using water from WDN, population and households using water both from WDN and other sources, population and households only using water from other sources.
	Water loss and its components
The system performance impacting on customers	Distribution of air and water volume in time and space
	The change of water quality in WDN, before and after private tank

Comparing with the list of data variables (section 4.4) necessary for calculating indicators, almost of all data are missing. The list of missing data is shown in Table 5.3. The missing data will be collected in according to proposed methods in section 4.4).

5.1.1 Field investigation to collect data of physical asset of WSS

To record data of physical asset such as map of pipeline network and locations of pump station, public tank, valve, tap, hydrant as well as their properties, investigators goes along with distribution network with the supports of hand GPS and a notebook. The specific points (e.g. bends, leakages) will be marked and take note important information (see Figure 5.1). Afterwards, all the data will be imported into ArcGIS to analyze and display the layouts of information. The Figure 5.1 shows steps to draw the map of WSS from working on-site to final production.

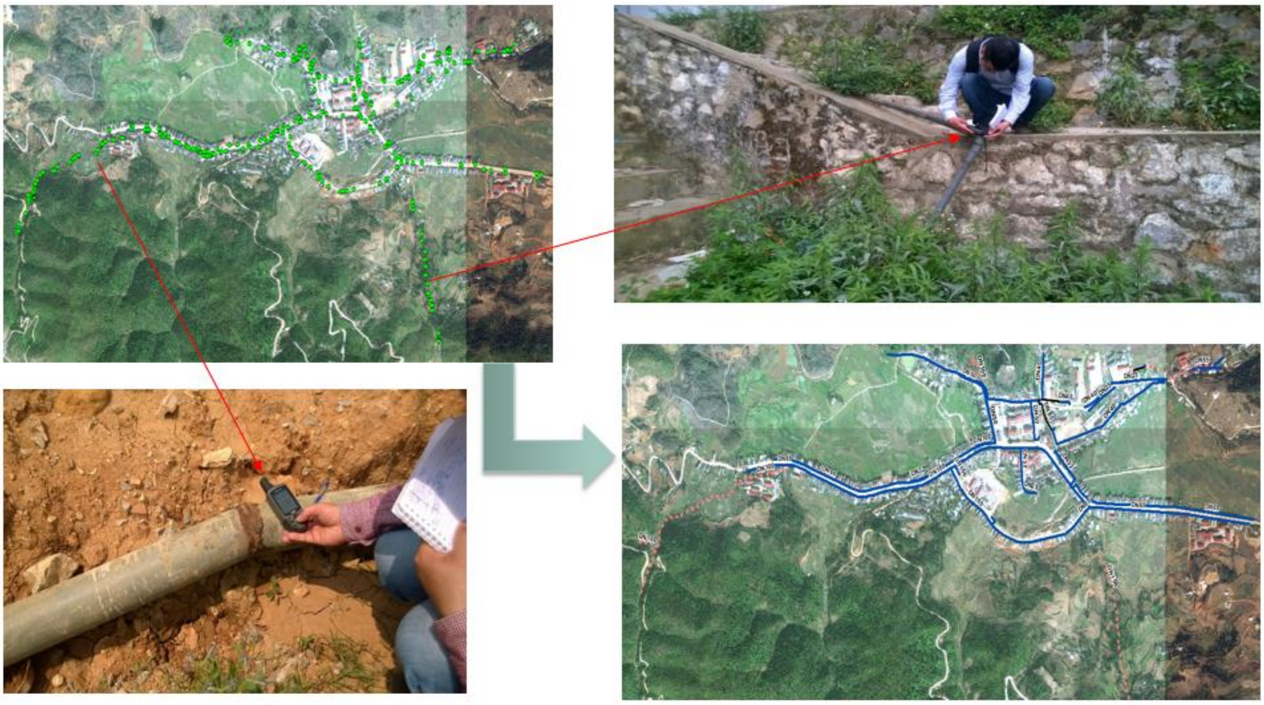


Figure 5.1. Steps to draw the map of WSS

Data of physical asset are collected from the field investigation comprising:

5.1.1.1 Water sources feeding water distribution network

Water distribution networks in Dong Van city are fed by Lang Nghien and To 5 pump stations. The former is exploited from surface water of cliffs. This water is collected and stored at cistern tank of Lang Nghien pump station to supply for Dong Van city. Due to this reason, water quality of this source is not stable in time, especially after heavy rain. This pump station is frequently operated from 8:00 to 20:00 in rainy season while operation time in dry season depends on amount of water available in storage tank. Lang Nghien pump station has been supplying water for 93.5% households of Dong Van city (Source: House-to-house investigation in 2016).

To 5 pump station is located at North of Dong Van city, near Ly Thuong Kiet Street. Water source supplying for this pump station is from drilled well 1 and 2. Well 1 is located at pump station while Well 2 is near Frontier Post. Water from Well 2 is moved to To 5 pump station through pipe Ø 65HDPE and pump for households of ward 5 of Dong Van city. However, because the amount of water of these two wells is too small, Water Utility in Dong Van city separated two wells in 2016. To 5 pump station pumps water from well 1 to supply for households. Well 2 is independent with To 5 pump station and supply water directly for some households in ward 5. The two wells only supply water for 55 households, one kindergarten, one primary school, and secondary school in ward 5 of Dong Van city (accounted for 6.5%).

The locations of Lang Nghien and To 5 pump stations see Figure 5.3 and pictures of them see Figure 5.2.

Figure 5.2. Lang Nghien and To 5 pump station

5.1.1.2 Pipeline network

The pipeline network can divide into 2 sectors:

- Sector 1: Pipes in central city (see Figure 5.4) are often underground. The rout of these pipes always go along two sides of road and near concrete drainage ditch.
- Sector 2: Pipes go across fields (rice, corn, etc.) or along nature drainage ditch (see Figure 5.5). These pipes are mostly not in use due to water scarcity.

Table 5.4. Statistics of pipelines

Type of pipe	Material	Length (m)
Ø100 (not in use)	Galvanized steel	1384.5
Ø100	Galvanized steel	3219.0
Ø65	Galvanized steel	2107.2
Ø65	HDPE	313.4
Ø65 (not in use)	HDPE	303.3
Ø50	Galvanized steel	376.3
Ø40	Galvanized steel	853.5
Ø32	Galvanized steel	291.9
Ø25	Galvanized steel	631.0
Total		**9480.1**

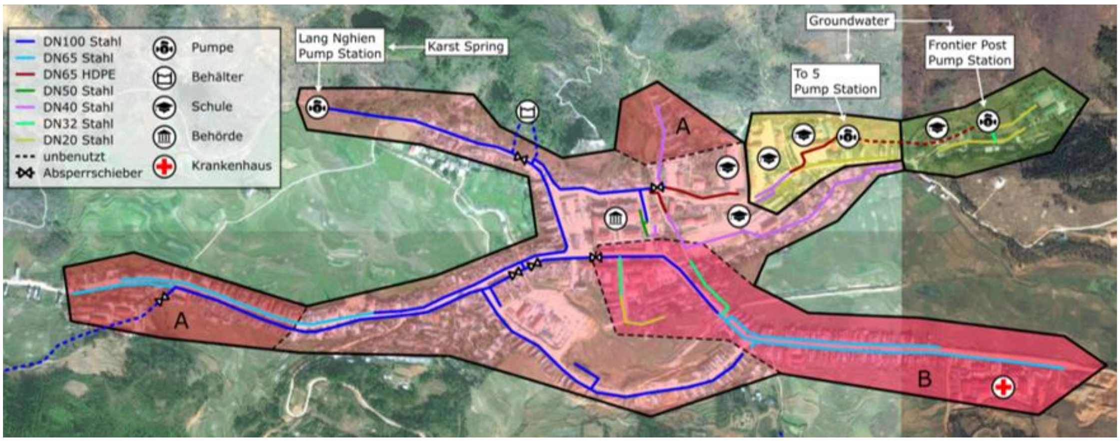


Figure 5.3. Map of water distribution network in Dong Van city

Figure 5.4. Pipelines in central city

Figure 5.5. Pipelines in the field

5.1.1.3 Public tanks and reservoirs

Public tanks are built at 6 locations marked from 1 to 6 (see Figure 5.3). Tank 1 located at Lang Nghien pump station (cistern tank) and tank 2 built at To 5 pump station (cistern-ground tank) are storage tanks of these stations while other tanks marked from 3 to 6 are not in use.

Seeing with naked eye shows that tanks not in use have big volume and quite good quality, and can use again after renovating. Especially, tank 3 is at an elevation of 1112 meters (near Lang Nghien pump station) with 203.8 m^3, which can use as an equalizing reservoir.

Table 5.5. Statistics of public tanks in Dong Van city

Name	Location	Type	Number of tanks	Total volume (m^3)	Material	Current situation
Tank 1	Lang Nghien pump station	Cistern	1	65.1	Reinforced concrete	In use
Tank 2	To 5 pump station	Cistern - ground	1	54	Reinforced concrete	In use
Tank 3	Old street	Ground	2	203.8	Reinforced concrete	Not in use
Tank 4	Doan Ket	Ground	2	50.9	Reinforced concrete	Not in use
Tank 5	Xom Moi	Ground	1	129.7	Reinforced concrete	Not in use
Tank 6	Near well 2	Ground	1	18.6	Reinforced concrete	Not in use
Total			**8**	**522.1**		



Figure 5.6. Tank 5 at Xom Moi (left) and tank 2 at To 5 pump station

5.1.1.4 Valves

There are 5 close valves and 1 sediment relief valve in water distribution network, but four of them are damaged (see Figure 5.3). More detailed information about these valves shows in Table 5.6.

Table 5.6. Statistics of valves in Dong Van city

Name	Location	Type	Current situation
Valve 1	3/2 road	Close valve	Close, damaged
Valve 2	Dong Van 1 bridge	Sediment relief valve	In use
Valve 3	Dong Van 1 bridge	Close valve	Open, damaged

Name	Location	Type	Current situation
Valve 4	Opposite People's committee of Dong Van	Close valve	In use
Valve 5	Old Street	Close valve	Open, damaged
Valve 6	Start point of Ly Thuong Kiet street	Close valve	close, damaged

Figure 5.7. Valve 4 opposite People's committee (left) and valve 5 at Old street (right)

5.1.2 House-to-house investigation to collect customer information

Investigators interviewed all water users in Dong Van city and fill in questionnaires. The house-to-house investigation provides a huge and detailed data of customers.

Figure 5.8. Interview customers during house-to-house investigation

The data extracted from questionnaires can be broken into some groups in the following:

5.1.2.1 Water users classified follow kinds of water sources

There are four kinds of water sources exploited by households including: (1) from water distribution network (WDN), (2) from water cliffs (M) – citizens using pipeline themselves to transport water from surface runoffs or water ravines in mountain to private tanks, (3) drilled well (W), and (4) rainfall (R). However, inhabitants often use multiple source due to water scarcity such as combining

WDN and M (WDN-M), WDN and W (WDN-W), and WDN and R (WDN-R). The percentage of households in according to kinds of water sources is shown in Table 5.7.

Table 5.7. Water users dividing into kinds of water sources

Type of source	Household	Percentage
WDN	475	45.20%
M	346	32.92%
WDN-M	129	12.27%
W	66	6.28%
WDN-W	24	2.28%
WDN-R	11	1.05%
Total	**1051**	

On the map, kind of water users are separated by different colors comprising water users only use water from WSS (WDN) marked by green color, only from mountain (M) marked by blue color, both from WDN and mountain (WDN-M) marked by Tuscan red color, only from drilled well (W) marked by red color, both form WDN and drilled well (WDN-W) marked by pink color, and both form WDN and rainfall (WDN-R) marked by Cretan blue color.

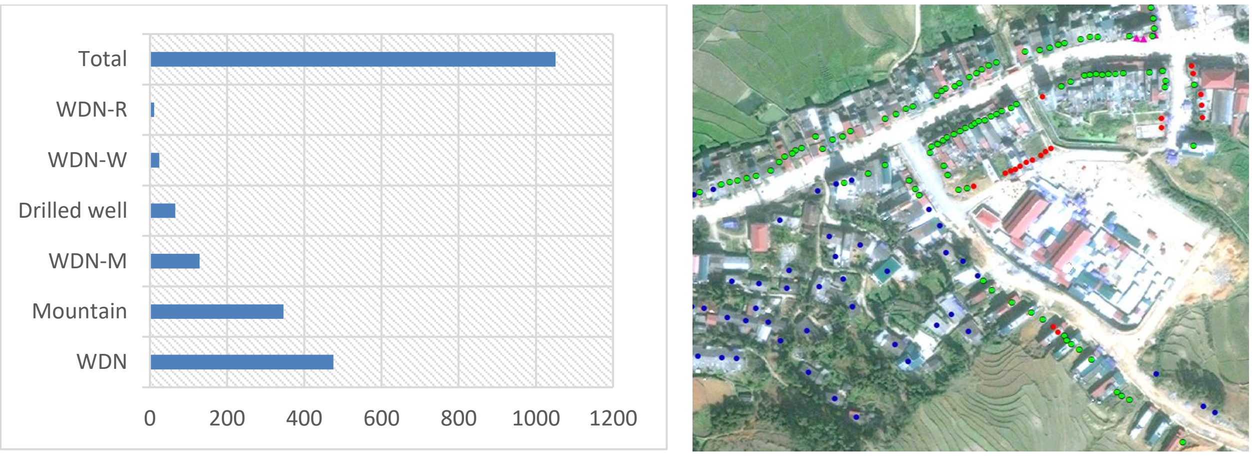


Figure 5.9. Water users dividing into kinds of water sources

These data are not only dispensable for whole process of performance evaluation, but also they are very important for improvement and extension of WSS.

5.1.2.2 Physical asset of water users interacting with WSS

Physical asset of water users interacting with WSS include private tanks, float valves and meters. According to location of private tank inside buildings, it can be located at underground (cistern tank), ground, and top of building (roof tank). Regarding to material, it can be made in of concrete and stainless steel. The data show that roof tank is the most common tank in Dong Van city with 778 tanks, followed by cistern tank and ground tank that accounts for 409 and 358 tanks, respectively. Besides, the percentage of float valve installed at roof tanks also surpass comparing with ground and cistern tanks. This can be explain that water users often have both cistern/ground tank and roof tank. Water from WSS will flow into cistern/ground tank but not enough pressure to reach roof tank. Water users often use ground/cistern tanks to store water, then use their pumps to pump water to roof tanks. They install close valve before ground/cistern tank and float valve at roof tank to automatically stop pumping when roof tank full.

Table 5.8. Statistics of private tank and float valve follow their positions inside buildings

Type of tank	**Number of tanks**	**Total volume (m^3)**	**% using float valve**
Stainless steel roof tank	728	1553	60%
Concrete roof tank	51	178	39%
Stainless steel ground tank	21	42	29%
Concrete ground tank	337	1556	7%
Cistern tank	409	2134	31%
Total	**1546**	**5465**	

Besides, types of combining between tank position and float valve that impact on the accuracy of water meter are also identified. Table 5.9 shows that combination types can be impacted by the presence of float valves to be (1), (3), (6) and (8). Thus, total buildings installed float valve that can negatively impact on meter inaccuracy is 331 buildings.

Table 5.9. Statistics of private tank and float valve follow combination type

No.	**Type of combination**	**Number**
1	Building having roof tank installed float valve	158
2	Building having roof tank without float valve	47
3	Building having ground/cistern tank installed float valve	3
4	Building having ground/cistern tank without float valve	73
5	Building having both roof tank and ground/cistern tank, but only roof tank installed float valve	84
6	Building having both roof tank and ground/cistern tank, but only ground/cistern tank installed float valve	26
7	Building having both roof tank and ground/cistern tank without float valve	122
8	Building having both roof tank and ground/cistern tank installed float valve	114
	Total number of buildings connecting with WDN having private tank	**627**

Data of customer meters are provided by Water Utility in Dong Van city (see Table 5.2).

5.1.2.3 Data of population and household

Data of households and population comprise total households in Dong Van city, total households and population connecting with WSS, households and population using 100% water from WSS, households and population using water both from WSS and other sources, and households and population only using water from other sources. The coordinates of all households are recorded and displayed on map as a data layout.

Table 5.10. Data of population and household

No.	Type of data	Unit	Statistic	Coordinate on map
1	Population in Dong Van city	person	4,231	
2	Households in Dong Van city	household	1,051	Yes
3	Population only using water from WDN	person	1,897	
4	Households only using water from WDN	household	475	Yes
5	Population using water both from WDN and other sources	person	636	
6	Households using water both from WDN and other sources	household	164	Yes
7	Population only using water from other sources	person	1,698	
8	Households only using water from other sources	household	412	Yes
9	Population where WDN reaches	person		
10	Households where WDN reaches	household		Yes

Besides, many other data related to water users such as occupation, complaints about quality of service, height of roof tanks, and so on are also collected in questionnaires.

5.1.2.4 Data related to inequality of distribution

Customers located at disadvantaged zones such as high or/and far zones have to look for solutions themselves to supplement the water deficiency over year.

Table 5.11. The level of average consumption of water users follow streets

Position	Name of road	Total households	Number of households connecting with WSS	Average consumption/ household/ day	Total private tank volume (m^3)
1-2-7	Old street	72	61	0.54	224
2-3-4	Nguyen Trai	48	48	1.11	107
3-6	Don Cao road	26	13	0.40	136
3-5	Ly Thuong Kiet	65	63	0.84	524
4-5	To 5	55	48	0.91	239
7-10	Right way of 3/2 road	137	97	0.47	799
8-9-11	Left way of 3/2 road	189	136	0.41	1156
12-13	Tran Phu	121	108	0.55	488
14-15	Dung Sung Lu	58	21	0.37	113
16-19	Left way of 19/5 road	45	35	0.75	172

Position	Name of road	Total households	Number of households connecting with WSS	Average consumption/ household/ day	Total private tank volume (m^3)
16-17-19	Right way of 19/5 road	114	105	0.52	699
9-11	Left way of 19/5 road	92	78	0.43	602

In Dong Van city, there are three common solutions such as using many water sources at the same time (water from cliffs, drilled well, and rainfall), using less water (less consumption), or building bigger private tank. Based on data from questionnaires, total households, number of households connecting with WSS, average consumption, total volume of private tanks in according to each street are calculated.

5.1.3 The method of observing customer meters

Test location: Chosen positions have to cover all advantaged positions (near supply sources and/or low positions), medium positions (middle WPN), and disadvantaged positions (far and/or high positions from supply sources) points in WPN. Based on this rule, 19 locations chosen in Dong Van city comprise near pump station and low points, middle points, and far and high points in WPN.

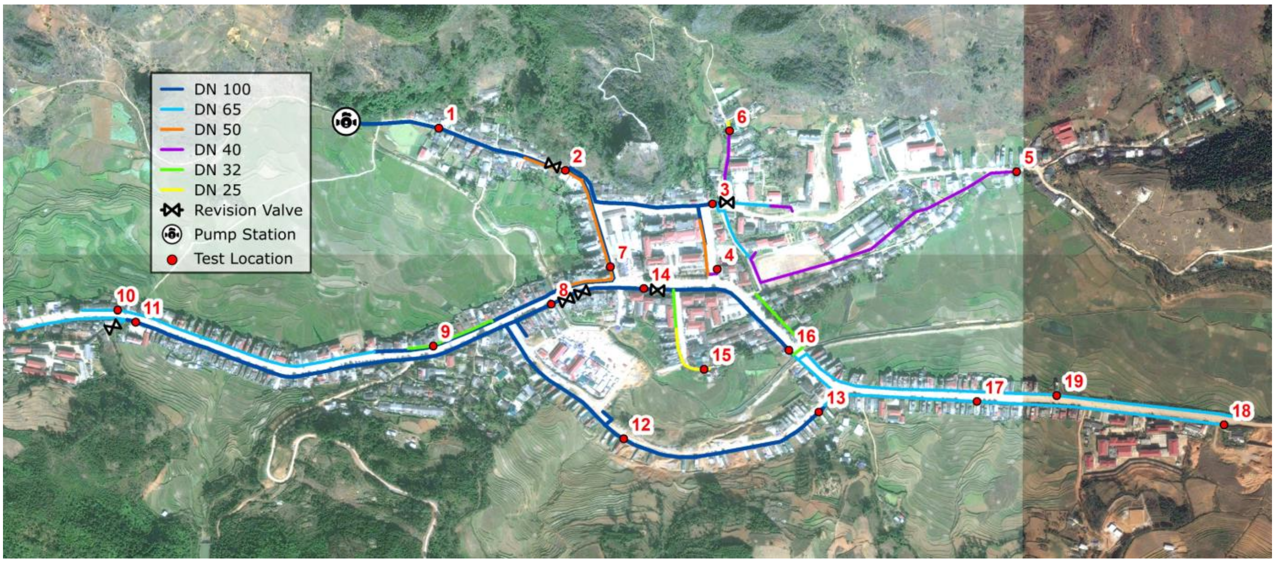


Figure 5.10. Locations of points to measure air volume

Test setup: (1) Mark specific positions of water consumption on the map including advantaged, medium and disadvantaged points (highest and lowest points, far and near water resource, etc.), (2) Check water meters and private tanks of buildings to make sure that these tanks are empty enough to store the water before providing water into WDN,

Parameter recorded: Record data at these positions comprising start time of providing water of service, time when meter start running, time when water coming, and indicators of water meters relevant to those times.

Test result: Table 5.12 shows the data extracted from result of experiment on-site including duration of air font and water flow coming to positions, duration of airflow, registered air volume as well as indicators of water meters at these times at 19 positions.

Table 5.12. The result of measuring air volume from on-site experiment

Position	Time when			Indicator of meter when		
	Meter running (airflow come)	Meter running (water flow come)	Stop collecting water	Meter running (airflow come)	Meter running (water flow come)	Stop collecting water
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
1	7:35:06	7:35:09	7:58:09	504.4496	504.4508	505.2488
2	7:35:15	7:35:19	7:55:09	451.28154	451.2823	451.9263
3	7:39:08	7:44:34	8:21:34	1389.3584	1389.3659	1389.8759
4	7:39:25	7:49:58	8:32:58	4754.68	4754.715	4755.733
5	7:51:56	7:56:34	8:34:34	1615.2603	1615.2734	1615.7534
6	17:32:12	17:46:24	18:28:24	308.3378	308.4464	308.6404
7	7:35:45	7:37:22	7:44:35	1168.41	1168.5071	1168.7077
8	7:38:43	7:38:43	9:05:43	1801.2592	1801.2592	1803.4032
9	7:50:52	7:52:18	8:13:37	513.3279	513.3403	513.53596
10	17:40:32	18:02:52	19:18:52	534.3815	534.5253	535.0353
11	17:53:25	18:27:43	20:40:43	6783.4722	6783.9386	6784.4716
12	7:40:56	7:47:24	8:14:53	243.1301	243.2475	243.4256
13	7:42:13	7:51:46	8:11:46	275.34856	275.7477	275.9577
14	7:39:02	7:39:17	7:58:00	212.4198	212.4210	212.6540
15	7:51:20	7:59:22	8:58:22	81.3892	81.4431	81.7641
16	7:47:22	7:49:06	7:59:00	10.1812	10.214	10.343
17	7:41:38	7:49:32	7:58:30	921.4258	921.5012	921.6768
18	8:00:32	8:00:32	8:11:32	465.6363	465.6363	465.7633
19	7:59:40	8:02:32	8:15:32	107.6358	107.817	107.972

The data extracted from Table 4.23 can be used to calculate some important parameters as follows:

5.1.3.1 Calculating apparent loss due to air volume

Total air volume registered by water meters of pipeline system at the beginning of supplying water is calculated based on data from Table 5.12. The steps of calculating air volume for whole distribution system are shown in Table 5.13, in which its columns is defined as follows:

- Column 1 is positions of test points
- Column 2 is air volume at test points = [(column 6 in Table 5.12) – (column 5 in Table 5.12)]x 365 days
- Column 3 is average value of air volume between two points:
  $(\text{Column }3)_i = [(\text{column }2)_{i-1} + (\text{column }2)_i]/2$

- Column 4 is the number of connections between two test points that is identified from house-to-house investigation and the pipeline network
- Column 5 is total air volume between two test points: Column 5 = (column 3) x (column 4)

Table 5.13. Estimating total air volume of pipeline system from on-site experiment

Position	**Air volume at point in one year (m^3)**	**Average air volume at points in one year (m^3)**	**Number of connections in pipe sections**	**Air volume at pipe sections in one in one year (m^3)**
(1)	*(2)*	*(3)*	*(4)*	*(5)*
1	0.33			
2	0.25	0.29	24	6.96
7	14.71	7.48	21	157.08
8	0.00	7.36	17	125.04
9	4.53	2.27	39	88.34
10	26.24	15.39	43	661.56
2	0.25			0.00
3	2.74	1.50	23	34.39
4	12.77	7.76	12	93.06
3	2.74			0.00
6	16.56	9.65	25	241.25
3	2.74			0.00
5	4.79	3.77	37	139.31
8	0.00			0.00
11	78.12	39.06	90	3515.40
8	0.00			0.00
12	42.85	21.43	45	964.13
13	72.85	57.85	48	2776.80
8	0.00			0.00
14	0.44	0.22	26	5.72
15	9.03	4.74	11	52.09
14	0.44			0.00
16	5.49	2.97	18	53.37
17	11.50	8.50	34	288.83
16	5.49			0.00
19	30.35	17.92	66	1182.72
17	11.50			0.00
18	0.00	5.75	68	391.00
Total air volume in one year				**10777.02**

The calculation result of Table 5.13 reveals that total air volume in a year is about 10777 m^3/year. This volume have to be smaller than total volume inside pipeline network. The pipeline network in

Dong Van city is often operated with one day of central valve closed and one day of central valve opened. For this reason, there is the difference of air volume in two cases.

Table 5.14. Calculate the total volume of air inside pipeline system if valve opened

Type of pipe	**Length (m)**	**Vacuum volume inside pipe (m^3)**
Ø100	3219.0	25.27
Ø65	2107.2	6.99
Ø65	313.4	1.04
Ø50	376.3	0.74
Ø40	853.5	1.07
Ø32	291.9	0.23
Ø25	631.0	0.31
	Total	**35.65**

Table 5.15. Calculate the total volume of air inside pipeline system if valve closed

Type of pipe	**Length (m)**	**Vacuum volume inside pipe (m^3)**
Ø100	2883.3	22.63
Ø65	617.7	2.05
Ø65	313.4	1.04
Ø50	376.3	0.74
Ø40	853.5	1.07
Ø32	291.9	0.23
Ø25	505.4	0.25
	Total	**28.02**

The air volume inside pipeline system when valve closed is smaller than it's in open. Total volume inside pipeline network in one year:

Air volume if opened valve = 35.65 x 183 = 6523.95 m^3

Air volume if closed valve = 28.02 x 182 = 5099.64 m^3

The total volume inside pipeline network in one year = 6523.95 + 5099.64 = 11623.59 m^3/year

The result shows that total air volume in a year (about 10777 m^3/year) is smaller than total vacuum volume inside pipeline network (11623.59 m^3/year). Thus, the measurement and calculation results are suitable.

In fact, the air volume going into buildings will be less than vacuum volume inside pipeline network because of some reasons such as (1) the pipeline network is incompletely vacuum during the period of without supplying water, (2) air can go out pipeline network through leakages of pipes, connections, valves, taps, and (3) air can be kept inside pipes where water cannot reach there.

5.1.3.2 Data for analysing inequality of distribution

Based on data from Table 5.12, many important data for analysing inequality of distribution system are defined such as duration of air and water coming to test points, duration of airflow and water flow, volume of air registered and water supplied, and average water flow at each test points. All these data are shown in Table 5.16. The columns in Table 5.16 are calculated in the following:

Column 2 = (Time when air coming to test point) - (Time of starting to pump water at pump station)

Column 3 = (Time when water coming to test point) - (Time of starting to pump water at pump station)

Column 4 = (Time when water coming to test point) - (Time when air coming to test point)

Column 5 = (Time when stop collecting water at test point) - (Time when water coming to test point)

Column 6 = (Indicator of meter when water coming to test point) - (Indicator of meter before meter running)

Column 7 = (Indicator of meter when stop collecting water) - (Indicator of meter when water coming to test point)

Column 8 = (column 7)/(column 5)

Table 5.16. Data for analysing inequality of distribution system

Pos.	Duration (hh:mm:ss)		Duration (hh:mm:ss)		Volume (l)		Average water flow rate (l/s)
	of air reach test point	of water reach test point	of airflow	of water flow	of air registered	of water supplied	
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
1	0:00:06	0:00:09	0:00:03	0:23:00	1.2	798	0.58
2	0:00:15	0:00:19	0:00:04	0:19:50	0.76	644	0.54
3	0:04:08	0:09:34	0:05:26	0:37:00	7.52	510	0.23
4	0:04:25	0:14:58	0:10:33	0:43:00	35	1018	0.39
5	0:16:56	0:21:34	0:04:38	0:38:00	13.12	480	0.21
6	9:57:12	10:11:24	0:14:12	0:42:00	108.6	194	0.08
7	0:00:45	0:02:22	0:01:37	0:07:13	97.1	200.6	0.46
8	0:03:43	0:03:43	0:00:00	1:27:00	0	2144	0.41
9	0:15:52	0:17:18	0:01:26	0:21:19	12.4	195.7	0.15
10	10:05:32	10:27:52	0:22:20	1:16:00	143.8	510	0.11
11	10:18:25	10:52:43	0:34:18	2:13:00	466.4	533	0.07
12	0:05:56	0:12:24	0:06:28	0:27:29	117.4	178.1	0.11
13	0:07:13	0:16:46	0:09:33	0:20:00	399.16	210	0.17
14	0:04:02	0:04:17	0:00:15	0:18:43	1.2	233	0.21

Pos.	Duration (hh:mm:ss)		Duration (hh:mm:ss)		Volume (l)		Average water flow rate (l/s)
	of air reach test point	of water reach test point	of airflow	of water flow	of air registered	of water supplied	
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
15	0:16:20	0:24:22	0:08:02	0:59:00	53.9	321	0.09
16	0:12:22	0:14:06	0:01:44	0:09:54	32.8	129	0.22
17	0:06:38	0:14:32	0:07:54	0:08:58	75.4	175.6	0.33
18	0:25:32	0:25:32	0:00:00	0:11:00	0	127	0.19
19	0:24:40	0:27:32	0:02:52	0:13:00	181.2	155	0.20

All data in Table 5.16 are indispensable for calculating indicators of inequality of distribution in water supply system.

5.1.3.3 Using this method to calculate apparent loss due to meter inaccuracy

In Dong Van city, it is impossible to use private tanks as net tanks because of some reasons: (1) Water meter are often connected with cistern tank or roof tank. The former is built by bricks or concrete and is underground, thus, definition of exact size of these tanks is impossible. The latter is frequently located at the top of building and connected with water meter through private pipes. The roof tank is usually made in of stainless that can identify the exact size. However, the accuracy of measurement result also depends on water volume inside private pipes that connecting between meter and roof tank; (2) Inaccuracy caused by intrinsic meter is often very small whilst the calculation of water volume inside cistern tank or roof tank due to above reasons has a significant error, which can lead to an inaccurate experiment result. For this reason, the experiment will use a mobile tank (a large bucket) as a net tank to store water after meter. Water directly flows from meter to bucket through small pipe. The exact size of bucket is audited by method of weighing water (1 liter = 1 kilogram). Then, the inaccuracy of meter is calculated by comparing the change of meter indicators before storing water and after the bucket full with net water volume inside the bucket. The net volume of bucket using for field experiment is 188.87 liter.

All water meters have been installed for households in Dong Van city since 2003. They are made in of Indonesia (727 meters), China (22 meters), Thailand (30 meters), and some other countries (5 meters). Thus, based on prevalence of meters in each classification, a representative group of 41 meters for experiment comprises 27 Indonesia meters, 5 Thailand meters, 7 China meters, and 2 other meters. Some pictures of field experiments see Figure 5.11.

Figure 5.11. Measuring accurate meter on site

The result from experiment on-site with 42 meters (see Table 5.17) shows that there are not the rule of changing meters inaccuracy follow time and origin. This causes the difficult to estimate apparent losses because of intrinsic inaccurate meters.

Table 5.17. The result of experiment on-site with 41 meters

No.	Name of household	Origin	Year of operation time	Volume follow meter (liter)	Net volume (liter)	Inaccuracy of meter (liter)
1	Truong Thi Quy	China	2006	192.8	188.87	3.9
2	Hoang Quoc Hung	Indonesia	2016	192.4	188.87	3.5
3	Den Van Lan	Indonesia	2015	190.2	188.87	1.3
4	Tran Doan Thang	Indonesia	2016	177.9	188.87	-11.0
5	Giang Mi Phu	Thailand	2009	208.0	188.87	19.1
6	Ha Van Chien	Indonesia	2016	190.1	188.87	1.2
7	Luong Man Tien	Indonesia		189.9	188.87	1.0
8	Nguyen Van An	Indonesia	2015	197.8	188.87	8.9
9	Old Health center	Indonesia	2013	202.7	188.87	13.8
10	Nguyen Van Trieu	China	2004	200.6	188.87	11.7
11	Nguyen Thanh Doan	Thailand	2009	191.0	188.87	2.1
12	Luong Thi Eng	China	2004	191.9	188.87	3.0
13	Ngo Quang Trung	China	2004	183.7	188.87	-5.2
14	Ly Pao Lin	Indonesia	2013	189.2	188.87	0.3

No.	Name of household	Origin	Year of operation time	Volume follow meter (liter)	Net volume (liter)	Inaccuracy of meter (liter)
15	Political center	Other	2003	202.4	188.87	13.5
16	Nguyen Van Bang	Indonesia	2016	189.1	188.87	0.3
17	Ren Van Luong	Indonesia	2009	189.7	188.87	0.8
18	Sin Min Su	China	2004	189.2	188.87	0.3
19	Giang Thi Mai	Indonesia	2012	190.4	188.87	1.5
20	Nong Quang Dan	Indonesia	2013	191.5	188.87	2.6
21	Nguyen Thi Thuyen	Indonesia	2012	195.6	188.87	6.7
22	Tran Anh Tuan	Thailand	2009	189.0	188.87	0.1
23	Bui Khac Da	Indonesia	2012	209.0	188.87	20.1
24	Vu Thi Ly	Thailand	2009	235.0	188.87	46.1
25	Sinh	Thailand	2009	134.0	188.87	-54.9
26	Tuan	Indonesia	2014	190.8	188.87	2.0
27	Cuong	Indonesia	2015	188.0	188.87	-0.9
28	Vu Van Dai	Indonesia	2010	191.6	188.87	2.7
29	Nguyen Van Cuong	Indonesia	2011	193.8	188.87	5.0
30	Hoa Cuong hotel	Indonesia	2013	198.2	188.87	9.4
31	Ethic school	Indonesia	2008	196.4	188.87	7.5
32	Dao Thi Phuong	Indonesia	2010	190.8	188.87	1.9
33	Hoang Minh Hoc	China	2005	195.1	188.87	6.2
34	Nguyen Khac Thanh	Indonesia	2015	178.1	188.87	-10.8
35	Bui Thi Tinh	Indonesia	2010	191.8	188.87	2.9
36	Bui Duc Duy	Indonesia	2009	193.6	188.87	4.7
37	Nguyen Gia Khanh	China	2005	188.5	188.87	-0.4
38	Giang Mi Tro	Indonesia	2014	195.7	188.87	6.8
39	Tran Thi Phuong	Other	2003	190.4	188.87	1.5
40	Nguyen The Duy	Indonesia	2014	196.4	188.87	7.5
41	Luu Bao Sinh	Indonesia	2013	191.44	188.87	2.6

In order to be convenient for estimation, water meters from Table 5.17 are divided into four groups in according to origin (Indonesia, Thailand, China, and other). Then, average inaccuracy of meter in whole system is calculated in the following equation:

$$\text{Average inaccuracy of meter in whole system (\%)} = \sum_{i}^{n} (\text{AIGxPWG})_i \quad \text{(Equation 5.1)}$$

Where

AIG (-): Average inaccuracy of each group

PWG (%): Percentage of meter group in whole system

Table 5.18. The intrinsic inaccuracy of meters follow origin

Country	**Number of meter tested**	**Average inaccuracy [liter per 188.87 liter]**	**Rate of meter follow origin [%]**	**Inaccuracy follow origin (liter)**
Indonesia	27	+3.4	92.73%	+3.15
Thailand	5	+2.5	3.83%	+0.10
China	7	+2.8	2.81%	+0.08
Other	2	+7.5	0.64%	+0.05
Average inaccuracy				+3.37
Percentage of intrinsic inaccurate meter per total water recorded by meter				**+1.79%**
Apparent loss due to meter inaccuracy in one year (1.79%x161,870 m^3)				**+2898 m^3**

However, note that the accuracy of weight that uses to check bucket volume is not audited. Thus, the result of this experiment is for reference only.

5.1.3.4 Calculating apparent loss due to float valve

As mentioned in Section 4.4.3.4, not all private tanks installed float valve have a negative effect on measuring inaccuracy of meter. Some combinations between private tanks (roof tank, ground and cistern tanks) and float valve can cause inaccurate meter including: (1) Building has roof tank installed float valve, (2) Building has ground/cistern tank installed float valve, (3) Building has both roof tank and ground/cistern tank, but only ground/cistern tank installed float valve, (4) Building has both roof tank and ground/cistern tank installed float valve.

From the result of house-to-house investigation, the number of connections having these combinations as follows:

Table 5.19. Statistics of combination type between private tank and float valve

No.	**Type of combination**	**Number of household**	**Percentage per total household**
1	Building has roof tank installed float valve	158	25.2%
2	Building has ground/cistern tank installed float valve	3	0.5%
3	Building has both roof tank and ground/cistern tank, but only ground/cistern tank installed float valve	26	4.1%
4	Building has both roof tank and ground/cistern tank installed float valve	114	18.2%
Total		**301**	**48.0%**

Table 5.19 show that only 48% water users in whole system having private tank installed float valve can have a negative effect on measuring inaccurate meters. However, the data from the house-to-house investigation indicate that households having both roof tank and ground/cistern tank are often located at medium or disadvantaged positions where have short time of water supply (from 3 to 5 hours per day). Thus, to collect enough water for the period without supplying water, ground/cistern tanks that are used as storage tank (before pumping roof tank by private pump) are often built with their sizes quite big (at least 5 m^3). These ground/cistern tanks is hardly full during operation time. For this reason, float valves in households having both roof tank and ground/ cistern tank rarely influence on water meter operation.

Therefore, only float valves installed inside tanks in buildings belong to advantaged zones such as zone 1 and zone 2 can cause a negative impact on meter operation. The percentage of these households located at advantaged zones is only 25.7% in total water users that can negative influenced on meter inaccuracy.

Besides, the impact of float valve on meter inaccuracy not only depends on the type of combination between private tank and float valve, but also is it contingent on water supply time of service, time of collecting water of household and water level inside private tank at time. For instance, time of consuming water of water user, the time of private tank nearly full or full, and water supply time of service have to occur at the same time, which causes a negative effect on measuring meter. In fact, three times meet each other not very usually. Thus, apparent loss due to float valve will be very small comparing with other components of apparent loss. For these reasons, the process of calculating water loss will ignore this component in this research.

5.1.4 Calculating SIV, availability and potentiality of water sources

5.1.4.1 Calculating SIV

Water sources feeding WDN comprise two pump stations Lang Nghien and To 5. The former often pumps water for WDN from 8:00 to 20:00 daily while the latter is operated with one day pumping and one day off.

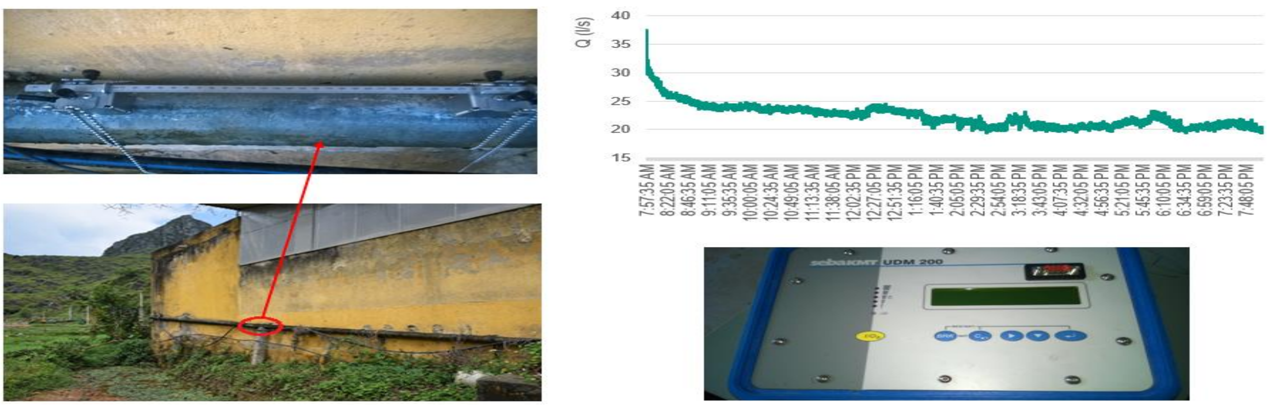


Figure 5.12. Measuring SIV at Lang Nghien pump station

SIV of these two stations is measured by device of UDM 200 from KaWaTech project at some times from 2014 to 2016. The device installed at outlet pipe of pump (see Figure 5.12) and the recorded data. These data will be used to estimate SIV.

Table 5.20. Measurement data of water input volume at Lang Nghien and To 5 pump station

Pump station	Date	Season	Total volume [m^3]	Flow [l/s]	Pumping time	Operation
Lang Nghien	27.02.2014	Dry season	494	17.26	7h 57min	daily
	13.11.2014	Beginning of dry season	532	16.64	8h 53 min	
	14.11.2014		500	13.27	10h 28min	
	02.07.2016	Rainy season	738	17.02	12h 2min	
	03.07.2016		680	14.34	13h 10min	
	06.07.2016		717	17.15	11h 37min	
To 5	31.07.2015	Rainy season	76	2.56	8h 17min	1 day pumping and 1 day off
	02.08.2015		67	-	-	
	04.08.2015		66	2.26	8h 9min	
	06.08.2015		78	2.66	8h 8min	
	08.08.2015		75	2.50	8h 21min	

Water flow of pumping is often biggest at the beginning of pumping because the pipeline system is vacuum at that time. Afterwards, pump flow will go down and reached a steady state. SIV depends on pump flow and pump time. From operation diary of two pump station, average operation time of Lang Nghien pump station in dry season is 8 hours 53 minutes and rainy season is 12 hours 9 minutes while this time at To 5 pump station is averagely 8 hours 2 minutes in both dry and rainy season. From these data, SIV is estimated for one year in Table 5.21.

Table 5.21. Estimate average water input volume per year based on measured data

No.	Day	Average flow [l/s]	Average operation time	Average input volume per day [m^3/day]	Average input volume per season [m^3/season]	Average input volume per year [m^3/year]
1	**Lang Nghien pump station**					202,813.6
	Dry season (Oct - Apr)	15.72	8:53:00	446.2	94600.4	
	Rainy season (May - Sep)	16.17	12:09:00	707.3	108213.2	
2	**To 5 pump station (Well 1)**					131,68.4
	Dry season (Oct - Apr)	2.50	8:02:00	36.1	7648.5	
	Rainy season (May - Sep)	2.50	8:02:00	36.1	5519.9	
Total dry season						**102,248.9**
Total rainy season						**113,733.1**
Total water input volume in one year						**215,981.9**

5.1.4.2 Availability of water sources

The main water source feeding WSS in Dong Van city is Lang Nghien pump station which has supplied water for 93.5% households of Dong Van city (source: House-to-house investigation in 2016). This source exploits surface water from cliffs that depending on the amount of rainfall and geological area. Based on weather conditions, Dong Van city are influenced by the tropical climate and does not belong to scarcity area of water. However, inequality of rainfall distribution through year and extreme difficulties of topography and geology cause economic water scarcity. Namely, the average annual rainfall is 1600 - 1700 mm/year, but not distributed evenly throughout the year (see Figure 5.13). The dry season lasts seven months, from October to April, with rainfall only of about 21 - 26% of the annual rainfall. The rainy season lasts five months, from end of April to end of September, and constitutes about 74% to 79% of the annual rainfall (Nguyet et al., 2012).

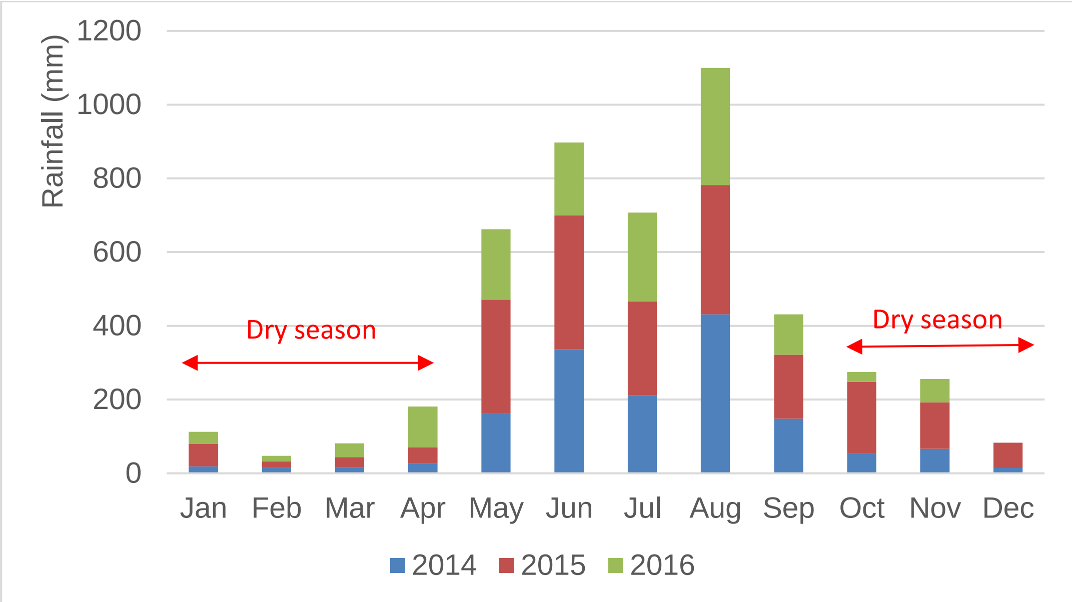


Figure 5.13. Distribution of rainfall from 2014 to 2016 at Dong Van city

Permanent surface flows are concentrated on major rivers, such as Seo Ho and Nho Que rivers that are far from and much lower in elevation comparing with Dong Van city. Temporary surface runoffs are generally formed only after heavy rains. Due to the high infiltration rates of Karst, water usually assembles in underground Karst cave networks forming underground water resource, which are potential resources for the water supply in those Karst areas (see Figure 5.14).

Figure 5.14. Ma Le 2 cave in Dong Van

Flow of water source supplying for Lang Nghien pump station measured at different times shows that water flow fluctuates significantly at different times in year completely depending on the amount of rainfall. For example, water flow at some times in February 2014 and March 2015 is around 10 l/s whilst it reaches nearly 60 l/s in June 2016. Comparing with the water demand of Dong Van city 216,204 m^3/year (6.86l/s), the availability of water source is much bigger than water demand.

Table 5.22. Water flow at different times of supply source

No.	Water flow [l/s]	Time	Average flow [l/s]	Average flow [m^3/year]
1	10.5	Feb-14	30.5	961,848
2	10	Mar-15		
3	28	Oct-15		
4	48	Oct-15		
5	56	Jun-16		

(Source: KaWaTech project)

However, from real operation of water undertaking in Dong Van city shows that Lang Nghien pump station only exploits a very small amount of water availability of the surface runoff in rainy season. Yet, many times in dry season, 100% water availability is exploited by Lang Nghien pump station, but it is still not enough for water demand. This explains that average operation time of the pump station in dry season is shorter than itself in rainy season.

It can be concluded that the water source feeding Lang Nghien pump station goes up and down rapidly over year. Due to this, the ability of current source is unlimited in rainy season, but it is not enough for water demand at many times during the time of 7 months of dry season.

Based on data measured in Table 5.22 and real operation of water undertaking in Dong Van city, the availability of water source in one year can be estimated equal to average value of all measured flow in Table 5.22 while the availability of water source in dry season is equal to SIV of Lang Nghien pump station.

5.1.4.3 Potentiality of water sources

As noted earlier, almost of all surface water usually assembles in underground Karst cave networks forming underground water resource due to the high infiltration rates of Karst, which are potential resources for the water supply. Namely, the result of water cave surveys in and around Dong Van city shows that there are many water caves with big amount of water in this areas such as Ma Le 1, Ma Le 2, Ma Le 3, Ma Le 4, Seo Ho, Tia Sang, and Sang Ma Sao. The survey measured water flow at some different times (dry and rainy season) in year. Therefore, total of potential water sources will fluctuate from 526 l/s to 9926 l/s equivalent to 16,594,243 m^3/year to 313,026,336 m³/year. In this research, the potentiality of water sources is preliminarily estimated to be 16,594,243 m³/year and 9,638,300 m³/dry season (calculating for 8 months of dry season with total smallest flows).

Table 5.23. Water flow of potential sources in and around Dong Van city

No.	Water cave	Water flow [l/s]	Time
1	Ma Le 1	108÷1286	2011÷2018
2	Ma Le 2	82÷2396	2011÷2018
3	Ma Le 3	122÷1936	2011÷2018
4	Ma Le 4	94÷1929	2015÷2018
5	Seo Ho	113÷1989	2015÷2018
6	Tia Sang	1.2÷300	2010÷2014
7	Sang Ma Sao	6÷90	2015÷2018
	Total	**526÷9926**	

(Source: KaWaTech project)

Comparing with the water demand of Dong Van city 216,204 m³/year (6.86l/s), the potentiality of water sources is much bigger than water demand. Nevertheless, such source is stored in deep underground Karst cave networks, which is impossible to exploit with traditional pumps. Thus, the potentiality of water source depends on the technology of exploiting water from Karst cave networks. In the range of KaWaTech project, the water would be pumped from Seo Ho hydro power plant to a storage tank Ma U (1 module 950.000; 2 modules 1.725.000l/d) by dint of the support of PAT-Pump. Subsequently, such water will be distributed to Dong van city (1 module 650.000 l/d = 237250 m³/year; 2 modules 1.410.000 l/d = 514650 m³/year) by gravity (Nestmann et al., 2014) (Figure 5.15).

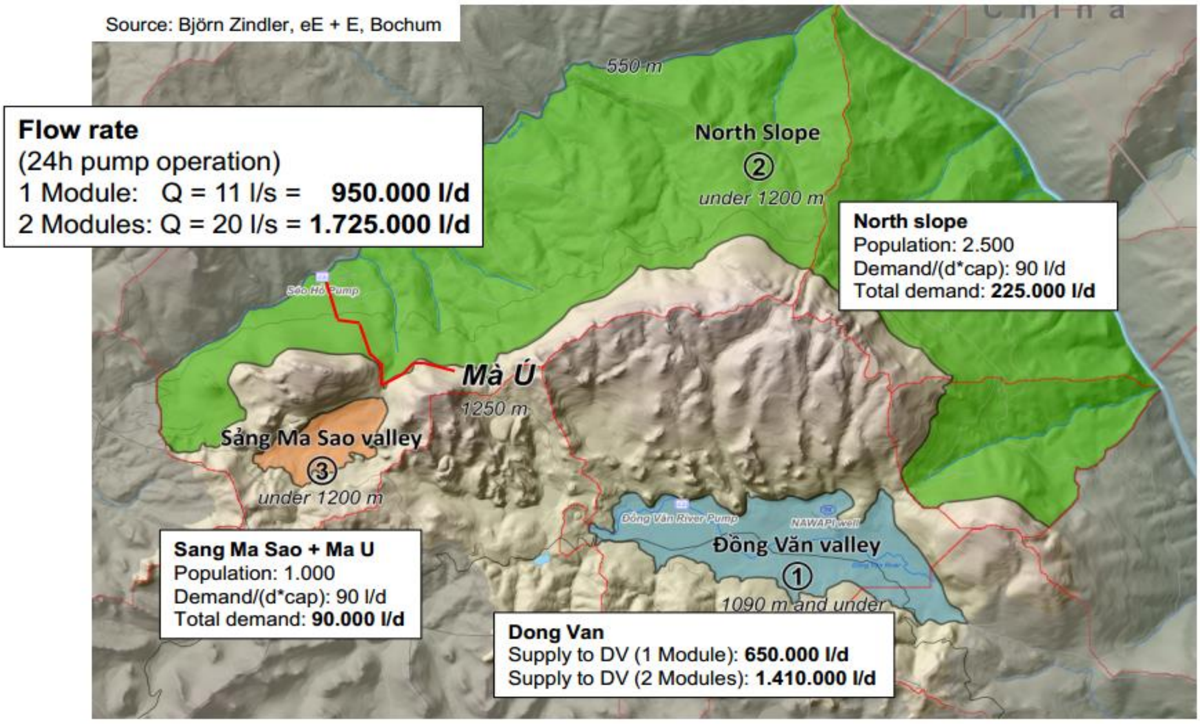


Figure 5.15. Water distribution of KaWaTech project

5.1.5 Water demand

Water demand includes water for households, business, governmental offices, public services, and water loss in distribution system. The method of calculating water demand is presented in section 4.4.5. Pursuant to Vietnamese Water Supply - Distribution System and Facilities Design Standard number TC33/2006 of Ministry of Construction, water volume per day per capita of Dong Van city (wd) is from 80 to 150 litter/day. In this research, wd chosen is 100 liter/day/capita and water loss in distribution system chosen is equal to 20% wd. The result of water demand is shown in Table 5.24.

Water demand in dry season = (water demand in one day) x (number of days in dry season from October to April) = (water demand in one day) x (212 days)

Water demand in a year equal to (water demand in one day) x 360.

Table 5.24. Calculating water demand for Dong Van city

No.	Type of water use	Formulation	WD in one day [m^3/day]	Total WD in one day [m^3/day]	WD in dry season [m^3/dry season]	WD in one year [m^3/year]
1	WD_{dm}	$\frac{wd \text{ x } P}{1000}$	423	**592**	**125,576**	**216,204**
2	WD_{ps}	10% WD_{dm}	42			
3	WD_{b}	10% WD_{dm}	42			
4	WD_{L}	20% WD_{dm}	85			

5.1.6 Using water balance to calculate components of water losses

The result of identifying water loss and its components is shown in Table 5.25. The calculation parameters is calculated in one year. The steps include in the following:

Table 5.25. Calculating components of water loss follow water balance

<table>
<tr><td rowspan="9">System input volume (1) = 215,982 m^3/year</td><td colspan="3">Authorized consumption (2) = 161,870 m^3/year</td></tr>
<tr><td rowspan="8">Water losses (3) = 54,112 m^3/year</td><td rowspan="4">Apparent losses (8) = -12,897 m^3/year</td><td>Airflow at the beginning of supplying water (4) = - 10,777 m^3/year</td></tr>
<tr><td>Metering inaccuracies (5) = - 2,898 m^3/year</td></tr>
<tr><td>Private tank and float valve (6) = 0 m^3/year</td></tr>
<tr><td>Unauthorized consumption (water theft) (7) = 778 m^3/year</td></tr>
<tr><td rowspan="3">Real losses (9) = 67,009 m^3/year</td><td>Leakage from storage tanks (10) = 0 m^3/year</td></tr>
<tr><td>Leakage from transmission mains (11) = 0 m^3/year</td></tr>
<tr><td>Leakage from distribution network (12) = 67,009 m^3/year</td></tr>
</table>

Note: The number inside parentheses shows the order of calculating. In the table, minus value means that the value of apparent loss negatively impacts on customers (customers have to pay for the volume of apparent loss although they do not consume it).

(1) System input volume

Total volume of water input in one year defined from Table 5.21 is 215,982 m^3/year (Average in two years 2014 and 2015).

(2) Authorized consumption recorded by customer meters

Total water consumption follow meter in 2014 and 2015 are 159,724 and 164,016 m^3/year (see Table 5.1), respectively. Hence, average consumption in two years is 161,870 m^3/year.

(3) Total water losses

Total water losses in one year is equal to total water system input volume minus total water authorized consumption = 215,982– 161,870 = 54,112 m^3/year.

(4) Airflow at the beginning of supplying water

In according to the result of estimating apparent losses due to airflow at the beginning of supplying water in section 5.1.3.1, the volume is 10,777 m^3/year.

(5) Total volume of apparent loss because of internal metering inaccuracy

Regarding to the result of calculating apparent loss due to internal metering inaccuracy in section 5.1.3.3, the volume is 2898 m^3/year.

(6) Total volume of apparent losses caused by float valve inside private tank in a year

As mentioned analyse in section 5.1.3.4, apparent loss due to float valve will be very small comparing with other components of apparent loss. Hence, the process of calculating water loss will ignored this component. It means that apparent loss due to float valve is equal to 0 m^3/year.

(7) Apparent losses due to water theft

Data from house-to-house investigation and going along pipeline system show that there are two households using water from WSS without installing meter. Both of them are former staffs of CERWASS. It is assumed that these two households consume water at the same with average consumption of households using 100% water from WDN (389 m^3/year). Therefore, apparent losses due to water theft in one year = 389 x 2 = 778 m^3/year.

(8) Total apparent losses in one year

Total apparent losses = Total their components = (-10777) + (-2898) + 725 + 778= -12,172 m^3/year

(9) Total real losses

Total real losses = (Total water losses) - (Total apparent losses) = 54,112 - (-12,172) = 66,284 m^3/year

(10) Real loss from storage tanks

Water sources stored at cistern tank before feeding water distribution network. Thus, the leakages (if has) from this tank will be not worth mentioning comparing with the leakages in distribution network. Therefore, water loss due to leakages of storage tank will be ignored in this research.

Real loss from storage tanks = 0 m^3/year

(11) Real loss from transmission mains

Water is directly distributed from supply sources to customers without transmission mains.

Real loss from transmission mains = 0 m^3/year

(12) Real loss from distribution network

Real loss from distribution network = (total real loss) - (real loss from storage tanks) - (real loss from transmission mains) = 66,284 - 0 - 0 = 66,284 m^3/year

5.1.7 Data related to the change of water quality in distribution network

5.1.7.1 Location and time schedule of taking samples

Parameters and positions of taking water samples: There are 5 parameters chosen including total coliform, E.coli, electrical conductivity (EC), turbidity, and PH. Due to the limitation of the number of available E.coli samples (20 samples), these samples will be taken at the most important locations including supply source (Lang Nghien pump station) and end points of pipeline network (see Figure 5.16) while water samples of other parameters are taken at many different points that cover distribution system (see Figure 5.17).

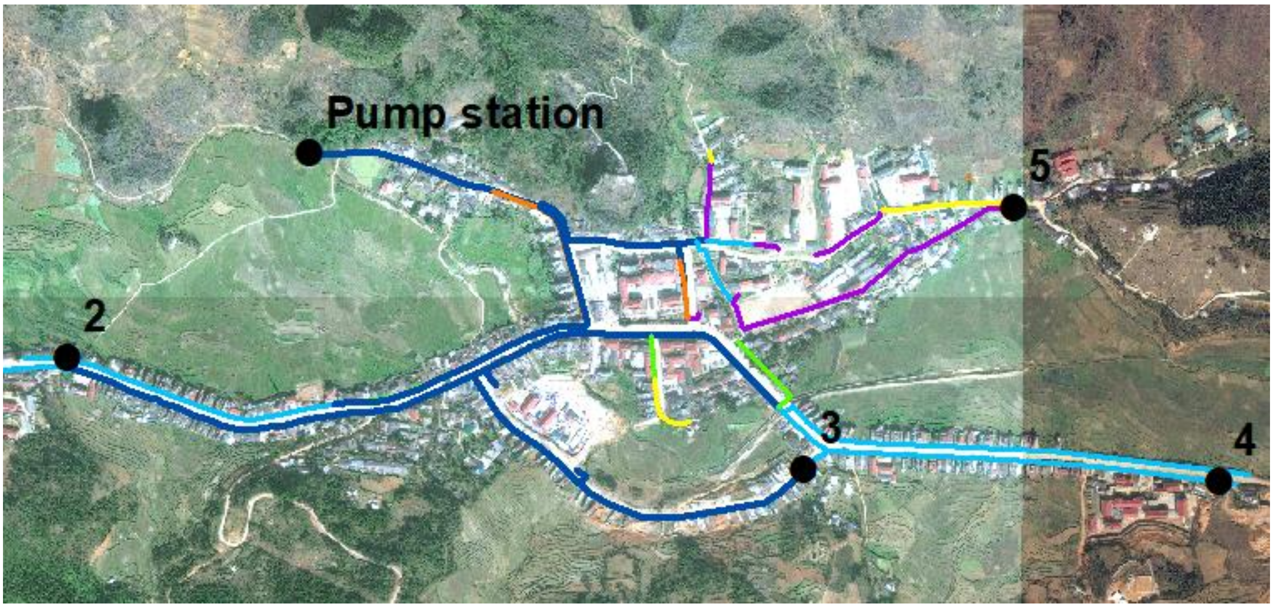


Figure 5.16. Positions of taking total coliforms and E. coli samples

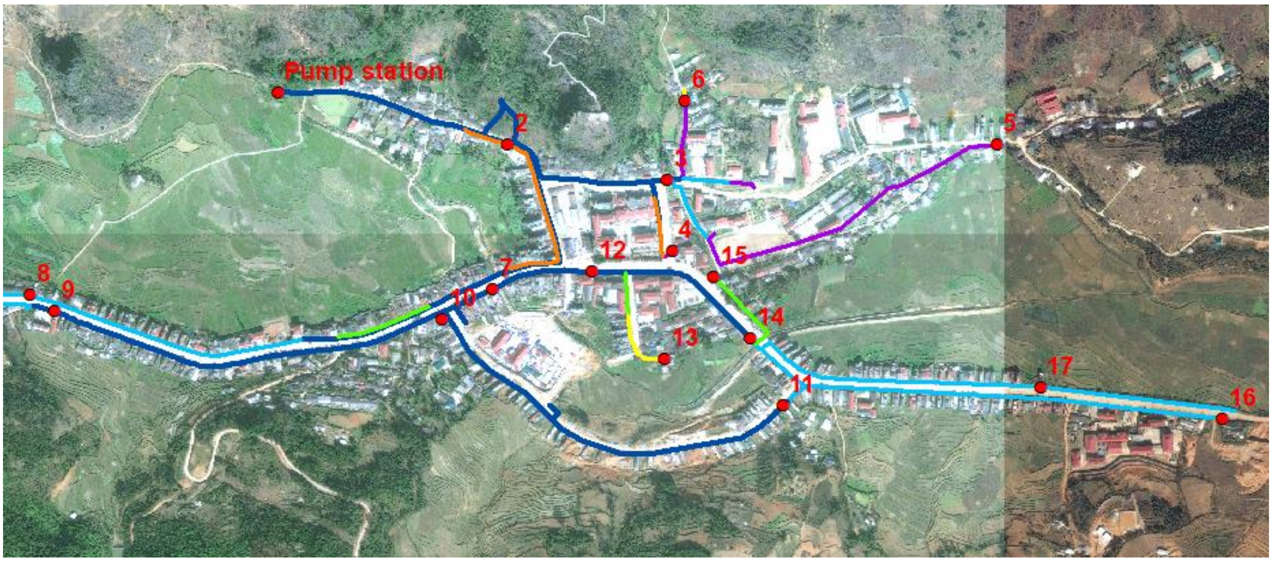


Figure 5.17. Positions of taking water samples for analysing Turbidity, EC, and PH

Test schedule: Water samples are taken at two times as soon as water coming to test points and after five hours of supplying water of service.

Table 5.26. Location and schedule of taking total coliform and E.coli samples

<table>
<tr><th rowspan="2">Test location</th><th rowspan="2">Test purpose</th><th colspan="2">Test time</th><th rowspan="2">Location taking sample</th><th rowspan="2">Total samples</th></tr>
<tr><th>First time</th><th>Second time</th></tr>
<tr><td>1</td><td>Test water quality before storage tank of Lang Nghien pump station</td><td>Right before pumping</td><td></td><td></td><td>1</td></tr>
<tr><td>1</td><td>Test water quality at output point of Lang Nghien pump station</td><td>Right after pumping</td><td rowspan="5">After 5 hours from first time</td><td></td><td>1</td></tr>
<tr><td>6</td><td>Test water quality of household at output point of pipe 1-2-3-6</td><td rowspan="4">Right after water reaches households at these locations</td><td rowspan="4">At input pipe before entering private tank and one sample at tap (after private tank)</td><td>4</td></tr>
<tr><td>7</td><td>Test water quality of household at output point of pipe 1-2-3-7</td><td>4</td></tr>
<tr><td>11</td><td>Test water quality of household at output point of pipe 1-2-3-11</td><td>4</td></tr>
<tr><td>14</td><td>Test water quality of household at output point of pipe 1-2-14</td><td>4</td></tr>
<tr><td>17</td><td>Test water quality at output point of To 5 pump station</td><td colspan="2" rowspan="2">5 hours after pumping</td><td>Right after pump station</td><td>1</td></tr>
<tr><td>18</td><td>Test water quality of household at output point of pipe 17-18</td><td>At input pipe before entering private tank</td><td>1</td></tr>
<tr><td colspan="4">Total samples</td><td></td><td>20</td></tr>
</table>

Table 5.27. Location and schedule of taking samples for EC, turbidity, and PH

Test location	Test purpose	Test time		Location taking sample	Total samples
		First time	Second time		
1	Test water quality at output point of Lang Nghien pump station	Right after pumping	After 5 hours from first time	After pump station or well	2
17	Test water quality at output point of To 5 pump station				2
19	Test water quality at output point of well 2				2
2	Test water quality of household at output point of pipe 1-2	Right after water reaches households at these locations	After 5 hours from first time	At input pipe before entering private tank and one sample at tap (after private tank)	4
3	Test water quality of household at output point of pipe 2-3				4
4	Test water quality of household at output point of pipe 3-4				4
5	Test water quality of household at output point of pipe 3-5				4
6	Test water quality of household at output point of pipe 5-6				4
7	Test water quality of household at output point of pipe 5-7				4
8	Test water quality of household at output point of pipe 3-8				4
9	Test water quality of household at output point of pipe 8-9				4
10	Test water quality of household at output point of pipe 9-10				4
11	Test water quality of household at output point of pipe 9-11				4
12	Test water quality of household at output point of pipe 9-12				4
13	Test water quality of household at output point of pipe 2-13				4
14	Test water quality of household at output point of pipe 13-14				4
15	Test water quality of household at output point of pipe 13-15				4
16	Test water quality of household at output point of pipe 13-16				4
18	Test water quality of household at output point of pipe 17-18				4
20	Test water quality of household at output point of pipe 19-20				4
Total samples					**74**

5.1.7.2 The result of analysing samples

The result of analyzing samples of total coliform, E. coli, EC, PH, and Turbidity at various positions is showed in the following tables:

Table 5.28. The result of E. coli and total coliforms

Position	**Time**	**Total coliforms [MPN/100ml]**		***E.coli* [MPN/100ml]**	
		Before tank	After tank	Before tank	After tank
Lang Nghien Pump station	First		54		4
	Second		51		3
4	First	162	66	16	9
	Second	102	54	12	9
7	First	461	166	28	12
	Second	46	192	9	23
11	First	236	22	31	15
	Second	11	126	10	47
14	First	1733	816	345	178
	Second	461	548	75	142
17	First	74		9	
	Second				
18	First	>2420	112	>2420	51
	Second				

Table 5.29. The result of analyzing EC, PH, Turbidity at positions

Position	**Time**	**EC [µS/cm]**		**pH [-]**		**Turbidity [NTU]**	
		Before tank	After tank	Before tank	After tank	Before tank	After tank
1	First	291	289	7.57	7.72	0.84	1.1
	Second	289	289	7.55	8.02	0.57	0.94
2	First	291	290	7.86	7.6	0.96	1.83
	Second	292	292	7.74	7.87	2.22	1.08
3	First	297	448	7.58	7.37	3.42	3.2
	Second	295	298	7.67	7.8	2.45	0.86
4	First	294	293	7.61	7.84	1.28	0.81
	Second	291	293	7.59	7.81	1.5	1.09
5	First	291	290	7.52	7.72	1.29	1.26
	Second	290	296	7.55	7.9	1.16	0.78
6	First						
	Second	291	295	7.58	7.84	1.62	0.67
7	First	295	293	7.74	7.78	2.85	0.8
	Second	291	295	7.68	7.74	1.13	0.91
13	First	289	292	7.62	7.74	1.29	1.45
	Second	289	294	7.62	7.97	1.6	0.88
14	First	295	290	7.94	7.6	1.76	12.53
	Second	292	292	7.59	7.92	5.06	1.46
15	First	297	289	7.65	8	0.99	1.15
	Second	290	289	7.68	8.01	1.19	1.23
16	First	291	294	7.67	7.85	0.8	1.24

Position	Time	EC [µS/cm]		pH [-]		Turbidity [NTU]	
		Before tank	After tank	Before tank	After tank	Before tank	After tank
	Second	292	294	7.56	7.79	1.02	1.44
8	First	292	292	7.62	7.96	1.35	0.8
	Second	289	298	7.55	7.9	0.67	0.7
9	First	273	340	7.58	7.8	14.6	13.45
	Second	290	408	7.55	7.07	2.94	2.2
10	First	294	297	7.84	8.13	5.31	11.45
	Second	292	297	7.57	8.15	2.46	1.17
11	First	300	295	7.69	7.84	6.55	1.06
	Second	292	293	7.66	7.77	0.7	0.85
12	First	297	305	7.65	7.96	0.98	0.59
	Second	292	302	7.57	7.85	0.81	0.61
17	First	340	375	7.96	7.95	15.32	13.98
	Second	350	373	7.99	7.82	1.14	2.54
18	First	774	376	7.48	7.88	9.14	1.95
	Second	369	377	7.69	7.89	2.8	2.18
19	First	385	361	7.45	7.55	9.63	0.82
	Second						
20	First	349	321	7.8	7.93	52.08	0.66
	Second	360	322	7.5	7.89	0.6	0.33
21	First	298	305	7.63	8.13	9.13	1.25
	Second	293	301	7.63	7.8	3.66	1.49

5.2 Application TPEs for WSS in Dong Van city

5.2.1 The boundary conditions: Water resources and water demand

5.2.1.1 Calculate PIs

Data variables necessary for calculating indicators of boundary condition group include SIV, water demand, availability and potentiality of water sources in dry season and in one year. All these data are calculated in section 5.1. Namely, SIV in one year and in dry season is estimated by water flow measured at different times in two years 2015 and 2016 as well as operation diary of pump station. Based on these data, SIV is calculated to be 102,249 m^3 in dry season and 215,982 m^3 in one year.

Water demand is calculated pursuant to Vietnamese Water Supply - Distribution System and Facilities Design Standard number TC33/2006 of Ministry of Construction, which includes domestic water, water for public service and business, and water losses in distribution system. Data for calculating water demand come from field investigation in 2016. Whereby, water demand in dry season and in one year of 2016 is 125,576 m^3 and 216,204 m^3, respectively.

The availability of water source over year surpasses many times water demand. However, in dry season 100% available flow of water source is exploited by Lang Nghien pump station, but it is not enough to supply for all customers. Based on data measured in Table 5.22 and real operation of water undertaking in Dong Van city, the availability and potentiality of water sources

Table 5.30. Data variables for group of boundary condition

No.	Data variables	Unit	Estimated value
1	SIV in one year	m^3/year	215,982
2	SIV in dry season	m^3/dry season	102,249
3	Water demand in one year	m^3/year	216,204
4	Water demand in dry season	m^3/dry season	125,576
5	Availability of water resources in one year	m^3/year	961,848
6	Availability of water resources in dry season	m^3/dry season	102,249
7	Potentiality of water resources in one year	m^3/year	164,810,290
8	Potentiality of water resources in dry season	m^3/dry season	9,638,300

Based on data variables in Table 5.30, indicators of boundary condition group are calculated in Table 5.31.

Table 5.31. Calculate PIs of boundary conditions

No.	PIs	Result	Benchmark	Weight
BC_{11}	Rate between water system input volume (SIV) and water demand in one year (%)	100%	4	3
BC_{12}	Rate between SIV and water demand in dry season (%)	81%	2	6
BC_{21}	Rate between available water resources and SIV in one year (%)	445%	4	2
BC_{22}	Rate between available water resources and SIV in dry season (%)	81%	1	4
BC_{31}	Rate between potential water resources and water demand in one year (%)	76229%	4	1
BC_{32}	Rate between potential water resources and water demand in dry season (%)	7675%	4	2
	Average mark of boundary conditions		**2.5**	
	Classification		**Water scarcity**	

5.2.1.2 Assess boundary conditions of system

The water source feeding WSS exploits surface water of cliffs that its capacity totally depends on the amount of rainfall and to geological structure. Dong Van city are influenced by the tropical climate with the average annual rainfall is 1600 - 1700 mm/year, but not distributed evenly throughout the year. The dry season lasts seven months, from October to April, with rainfall only of about 21 - 26% of the annual rainfall. The rainy season lasts five months, from end of April to end of September, and constitutes about 74% to 79% of the annual rainfall (Nguyet et al., 2012). Besides, due to the high infiltration rates of Karst, rainfall usually assembles in underground Karst cave networks forming underground water resource, which are potential resources for the water supply in those Karst areas.

For these reasons, the capacity of current water source goes up and down rapidly over year. In fact, indicators of availability of water source prove that the availability of water source over year (BC_{21}) is more four times bigger (445%) than SIV of Lang Nghien pump station, but it (BC_{22}) is not enough (81%) for water demand during dry season. Due to instability of current water source over year, SIV meets 100% water demand in a total year (BC_{11}), but only meets 81% water demand during the time of dry season (BC_{12}).

The potentiality of water sources from underground Karst cave networks is quite diversity in and around Dong Van city. Data from KaWaTech project show that there are many water caves with big amount of water in this areas such as Ma Le 1, Ma Le 2, Ma Le 3, Ma Le 4, Seo Ho, Tia Sang, and Sang Ma Sao with total flow fluctuating between 526 and 9926 l/s over year. The capacity of these sources is thousand times bigger than water demand of Dong Van city. The indicators of potential water source (BC_{31} and BC_{32}) are calculated with the smallest potential flow (526l/s). BC_{31} reveal that the capacity of potential water over year is around 762 times bigger than water demand whilst the capacity of potential water during the time of dry season (BC_{32}) is also 77 times bigger in comparing with water demand. Nevertheless, such sources is stored in deep underground Karst cave networks, which is impossible to exploit with traditional pumps. Thus, the potentiality of water source depends on the technology of exploiting water from Karst cave networks.

In brief, total capacity of available water sources all surpasses many times comparing with water demand over year, but it is not enough for water demand at many times during the time of 7 months of dry season. As the result, the average mark of boundary condition of system is 2.5 equivalent to classification of water scarcity in benchmark. Moreover, water input volume, in fact, is only enough to provide for small percentage of population due to many reasons as follows:

- The water source feeding WSS exploits surface water of cliffs that are vulnerable under the impact of weather and human factors.
- Ineffective distribution: High rate of water losses, water distribution in WDN being not equitable in space and time. The advantaged positions can collect water anytime as long as

water being supplied in system while the disadvantaged ones can receive water some hours per day with a small flow and big amount of air volume as well as worse water quality

- The lack of enough big storage tanks to store water in the plentiful period and supplement for water scarcity time,
- The water waste of households at advantaged positions is also one of reasons that lead to water scarcity in WSS,
- The pipeline system has not covered all water users in service areas

5.2.2 The performance of total system

Data variables for calculating indicators of system performance are identified in section 5.1. Namely, variables of physical asset are extracted from field investigation such as length of pipes in use and whole system, volume of public tank in use and whole system, number of valves in use and whole system. Number of households including households where WDN reach, households connecting with WSS, households in service area, households connecting with WSS and at the same time using other sources are calculated from house-to-house investigation. Volume of water losses and their components is calculated by water balance and the method of observing customer meters. All values is shown in Table 5.32.

Table 5.32. Data variables of system performance group

No.	Data variables	Value
1	Total length of pipes in use (m)	7792.3
2	Total length of pipes of WDN (m)	9480.1
3	Total households where WDN reach (households)	818
4	Total volume of public tanks in use (m^3)	119.1
5	Total volume of public tanks of WDN (m^3)	522.1
6	SIV in one year (m^3/year)	215,982
7	Total valves in use (number of valves)	2
8	Total valves of WDN (number of valves)	6
9	Total households connecting with WSS (households)	639
10	Total households in service area (households)	1051
11	Total households connecting with WSS and at the same time using other sources (households)	164
12	Total hours of water supply service in a year (hh:mm:ss)	10:05
13	Total volume of water losses in one year (m^3/year)	54,112
14	Total air volume coming to customer meters in one year (m^3/year)	10,777

No.	Data variables	Value
15	Water consumption recorded customer meters in one year (m^3/year)	161,870
16	Total volume of apparent losses due to other reasons in one year (m^3/year)	2120
17	Total volume of real losses in one year (m^3/year)	67,009
18	Unavoidable real losses in one year (m^3/year)	10,751

Based on above data variables, all indicators of total system performance are calculated in Table 5.33.

Table 5.33. Calculate PIs of the total system performance

No.	PIs	Result	Benchmark	Weight
I	**Physical asset of distribution system**		**1.6**	**3**
PS_1	Pipes in use (%)	82%	2	2
PS_2	Coverage of WDN (%)	78%	2	3
PS_3	Volume of public tanks in use (%)	23%	1	2
PS_4	Water storage capacity of public tanks in use (days)	0.2	1	1
PS_5	The number of valves in use (%)	33%	1	1
III	**Coverage of water supply service**		**1.5**	**3**
PS_7	The rate of households connected with WSS per total households (%)	61%	1	3
PS_8	The rate of households using 100% water from WSS per total households (%)	45%	2	3
IV	**Water supply time of service**		**2**	**1**
PS_9	Average operation time of water supply service per day (hour/day)	10:05	2	1
V	**Water losses**		**3.0**	**3**
PS_{10}	The rate between Non-Revenue Water and SIV (%)	25.1%	2	3
PS_{11}	Infrastructure leakage index: ILI (-)	6.2	3	3
PS_{12}	Apparent loss index: ALI (-)	1.6	4	3
	The average performance of total system	**2.02**		

The average mark of total system performance is 2.02 equivalent to classification of poor operation and management in benchmark. The inefficiency of operation and management come from some reasons such as low coverage of water supply service and inefficiency of using physical asset. The performance of total system is evaluated in according to subgroups in the following:

5.2.2.1 Efficiency of using physical asset

The benchmark of this subgroup is 1.6, which is classified in lowest level in evaluation standard (very bad). It means that physical asset of WSS in Dong Van is deteriorated extremely. For example, the percentage of pipelines in use accounts for 82%, even the coverage of pipeline network covering water users is lower with around 78%. Public tanks and valves even have a much bigger waste with their rate in use being 23% and 33%, respectively. The waste of using public tank (only 23% in use) leads to a fact that if water sources stop supplying water for WDN, the storage capacity of public tanks will solely be enough water for WDN in 0.2 day equivalent to approximately 5 hours. The waste of infrastructure asset comes from some reasons:

- Water sources drained: There were two water sources (Doan Ket and Xom Moi sources) providing water for WDN in Dong Van city in the past. But, these sources were drained in recent years; as a results, 1384.5m pipelines (see Table 5.4) connecting between such sources and WDN become waste. Besides, 6 public tanks with total volume 403 m^3 and two valves are not in use due to this reason (see Table 5.5 and Table 5.6).
- Some pipes located high positions in WDN are also not in use because water cannot reach these positions such as pipes at North (zone 8) and West direction (zone 3).
- Some other infrastructures are damaged or degraded because of the lack of maintenance.

5.2.2.2 The coverage of water supply service

The benchmark of this subgroup is 1.5. It means that the coverage of water supply service is very low and is classified in lowest level of evaluation standard. Namely, the percentage of households connected with WSS is about 61% in total households of service area. In addition, 26% households in total households connecting with WSS use other water sources such as drilled wells, rainfall, or water from cliffs. The households using both water from WSS and other sources only connect with WSS as a contingency measure in case of other source drained or not enough water. In fact, water consumption level of these households are often much lower (or even no consumption) than households using 100% water from WSS. The low percentage of households using water from WSS originate from some causes:

- The quality of water supply service has not met inhabitants' requirement. Firstly, water is directly pumped from Lang Nghien and To 5 pump stations to water users without any treatment, thus, water quality is low and not stable, especially at certain times such as after heavy rain. Secondly, the pipeline system has not covered all water users in Dong Van city. Besides, quality of distribution service is still extreme limited such as inequitable distribution, low pressure, and intermittent supply.
- Diverse water sources: There are some water sources in Dong Van city including water from high mountain, drilled well and rainfall. Citizens will decide water sources depending on water and service quality, expenditure, and convenience.
- The water price of business is triple comparing with households. For this reason, many hotels and restaurants have to look for other water sources instead of water from WSS to save their operation cost.

5.2.2.3 Water supply time of service

Average time of Lang Nghien pump station pumping water for WDN is about 10 hours 31 minutes in one year while To 5 pump station pumps about 4 hours 01 minute on average per year. Based number of customers supplied water by each pump station (Lang Nghien 93.5%, To 5 6.5%), water supply time of system is 10 hours 5 minutes on average per year. Comparing with the benchmark, the supply time is classified in level 3 of evaluation standard. The water supply time of service is short because of some causes such as water scarcity during dry season, high difference in elevation among water users, and limitation of pump technology.

5.2.2.4 Water losses

The benchmark of this subgroup is 3.0 and is classified in good level of evaluation standard. The percentage of non-revenue water accounts for about 25% total water system input volume. However, due to high rate of air volume that occupies 7% water consumption recorded by customer meters, real loss, in fact, accounts for 31% SIV. The indicators of water losses show that air volume at the beginning of supplying water is the main reason lead to apparent losses while apparent losses due to other reasons are not worth mentioning. Besides, there is no main transmission and all public tanks are underground in Dong Van city, hence, all real losses occur at leakages on distribution system. Moreover, the infrastructure leakage index that reflect the rate between current real losses and unavoidable real loss is 6.2. It means that the potentiality of reducing real loss is very big. From house to house investigation and going along with pipeline system show that almost of all leakages occur at positions:

- Connections between main pipes with water users. Each connection often comprises close valve and water meter. Leakages usually happen at connection points: (1) between main pipe and private pipe, (2) valve before water meter, and (3) water meter
- Pipes DN40 of ward 5, DN32 of 19/5 road (near Agriculture bank) and DN100 of Tran Phu road: These pipes go through stadium, Dong Van Ethnic Boarding High School, and household and are under buildings' foundation. Therefore, the structure process of these buildings caused pipe breakages. Besides, due to this, the repair and maintenance of these pipes are impossible
- Pipes DN25 (belong to ward 5) that distribute water from To 5 pump to primary and secondary schools, and households of ward 5 are inside wastewater ditch, thus, waste water can go into pipes and causes contamination.
- Pipes DN25 of road to High Frontier Station, and DN25 of road to Frontier Post are put on the road. Some breakages is consequent by vehicles.

5.2.3 The system performance impacts on individual customers

5.2.3.1 Inequality of distribution

The inequity of distribution reveals in sides: Time and flow distribution, water consumption level, and inaccuracy of water meter due to airflow at the beginning of the network filling process at various positions. To be easier for evaluating inequality of distribution, water supply area of service is broken into 9 zones based on elevation, zone position in WSS, and pipe diameter. The detailed description of every zones is introduced in Table 5.34.

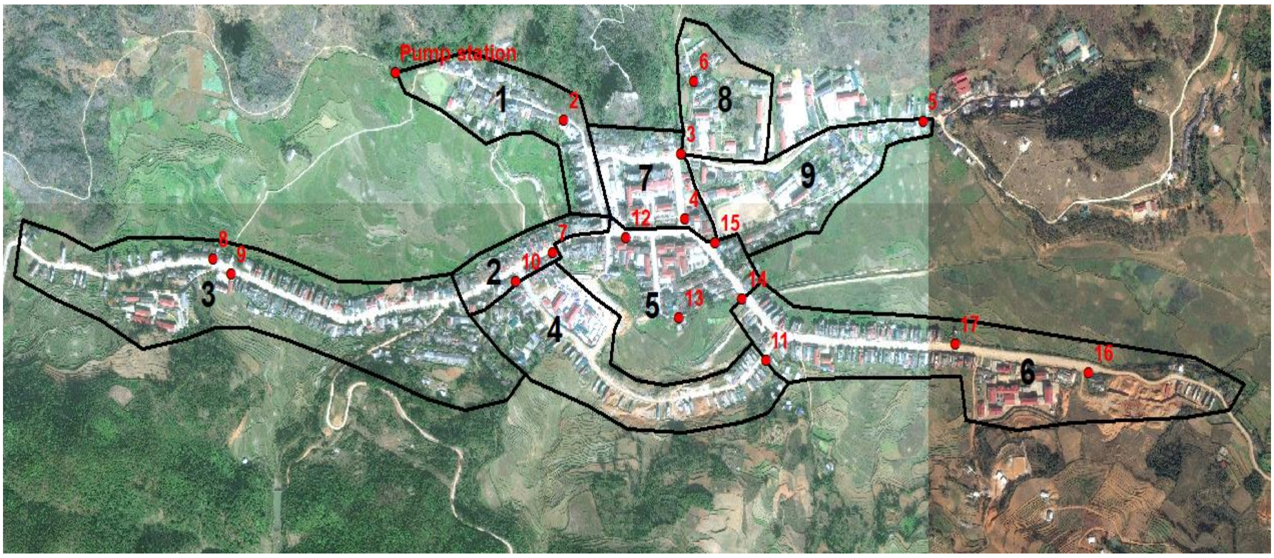


Figure 5.18. Supply zones in WSS (black color) and test points (red color)

The difference in elevation is very large approximately 45m (from the lowest point 1177m to the highest point 1222m). The two highest zones are zone 3 and 8 where some points reach over 1220m in elevation. Moreover, pipe diameter at these two zones is smaller than central zones with Ø65 at zone 3 and Ø32 at zone 8. Zone 6 and zone 9 have lower elevation than others, but water before reaching to these zones has to flow through quite high zones (zone 5 and 7), thus, water flow at these two zones will be dominated by others. Besides, the two zones also have pipe diameters smaller than central ones (Ø65 at zone 6 and Ø40 at zone 9). Zone 4 located at central

Table 5.34. The description of water supply zones

Zone	Zone name	Description
1	Near pump station	Zone near pump station with elevation from 1186m to 1199m, and pipe diameter Ø100
2	Low and middle zone	Low zone with elevation from 1182m to 1197m and located at middle WSS, and pipe diameter Ø100
3	Highest and end zone	Highest and end zone with elevation from 1204m to 1222m, and pipe diameter Ø65
4	High and middle zone	High and middle zone with elevation from 1190m to 1202m, and pipe diameter Ø100
5	Little high and middle zone	Little high and middle zone with elevation from 1184 to 1192, and pipe diameter Ø100
6	Low and end zone	Low and end zone with elevation from 1178m to 1185m, and pipe diameter Ø65

Zone	Zone name	Description
7	Little high and middle zone	Little high and middle zone with elevation from 1186m to 1205m, and pipe diameter Ø100
8	Highest and end zone with small pipe	Highest and end zone with elevation from 1201m to 1221m, and pipe diameter Ø32
9	Low and end zone with small pipe	Low and end zone with elevation from 1177m to 1188m, and pipe diameter Ø40

In summary, zone 1 and 2 are the most advantaged positions (near pump station and low in elevation, and big pipe diameter Ø100), followed by group of central zones (zone 5, 7 and 4 with big pipe diameter Ø100, and not too much high in elevation). Zone 6 and zone 9 are located at low and end of the system, thus water comes to these areas after middle zones (5 and 7). Finally, the most disadvantaged zones are 3 and 8 because these two zones have the highest elevation and smaller pipe diameters than others.

The inequality of distribution will be evaluated in according to 8 indicators including: IC_1 – distribution time, IC_2 – distribution of water flow, IC_3 – distribution of air volume, IC_{41} and IC_{42} – percentage of households with WSS, IC_{51} and IC_{52} – consumption level, and IC_6 – volume of private tank.

5.2.3.1.1 Indicator IC_1 – the time of water distribution in system

From above analyses, it may estimate that water will flow to zone 1 and 2 first, followed by middle zones such as zone 7, 5, 4, 9, and 6. Zone 3 and 8 will receive water finally. However, it is impossible to estimate exactly the order and time water coming to zones. By using the method of observing customer meters, the time of water coming to zones can be identified in Table 5.35. In this table, time of water coming to all connections of each zone (column 4) is defined based on time of water coming to test points in each zone. Time of available water at all connections of each zone (column 5) is equal to average operation time of Lang Nghien pump station in 2016 (12 hours 9 minutes) minus column 4. IC_1 (column 6) is the rate between time of available water at all connections of each zones (column 5) and average operation time of Lang Nghien pump station in 2016 (12 hours 9 minutes). Finally, score of each zone (column 7) is scored by comparing the values of IC_1 in column 5 with benchmark. Besides, relied on data from house-to-house investigation, the percentage of households collecting water in time is calculated in Table 5.35 and Figure 5.19.

Table 5.35. Calculating indicator IC_1 of zones

Zone	Description	% households of each zone	Time of water coming to all connections of zone	Time of available water at all connections of zone	IC_1 (%)	Mark
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
1	1-2-7	7%	in 10 minutes	11 hours 59 minutes	99%	5
2	7-8-9	12%	in 20 minutes	11 hours 49 minutes	97%	5
3	9-10-11	15%	in 11 hours	01 hours 9 minutes	9%	1

Zone	Description	% households of each zone	Time of water coming to all connections of zone	Time of available water at all connections of zone	IC_1 (%)	Mark
4	8-9-12-13	14%	in 20 minutes	11 hours 49 minutes	97%	5
5	8-14-15-16	9%	in 25 minutes	11 hours 44 minutes	97%	5
6	16-17-18-19	26%	in 30 minutes	11 hours 39 minutes	96%	5
7	2-3-4	5%	in 10 minutes	11 hours 59 minutes	99%	5
8	3-6	2%	in 11 hours	01 hours 9 minutes	9%	1
9	3-5	9%	in 25 minutes	11 hours 44 minutes	97%	5

Generally, the calculation result shows that customers at almost of all zones can obtain water after 30 minutes pumping water of service (equivalent to about 80% households), except zone 3 and zone 8 where water comes to all connections in around 11 hours. Namely, all households of two zones closest to pump station (zone 1) with 13% households can collect water in 10 minutes, followed by zones located at middle positions of WSS (zone 2, 4, and 5) that account for 36% of households. Afterwards, households located at low and far zones such as zone 6 and 9 (35% households) can obtain water in 30 minutes. Water reaches final positions of WSS (zone 3 and 8) in 11 hours after other zones collecting enough water. Due to this, IC_1 of zone 3 and 8 is only 9% (corresponding to mark of 1 in benchmark) while IC_1 of the remaining zones is not less 95% (equivalent to mark of 5 in benchmark).

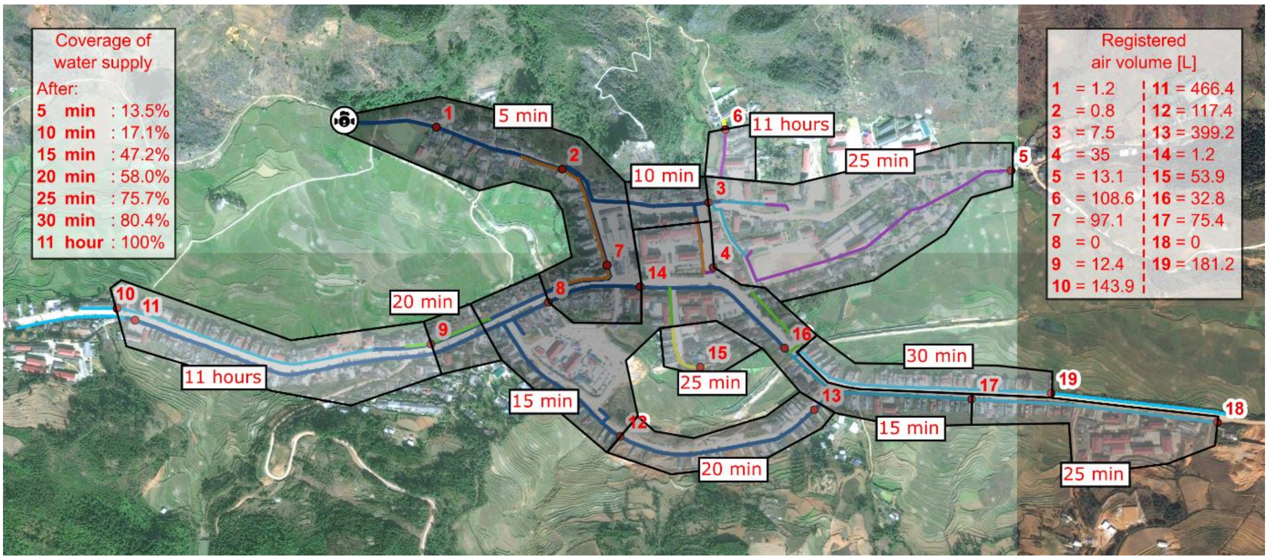


Figure 5.19. The time of water distribution

In brief, the difference in available time to collect water at zones is extreme inequality among zones, especially at zone 3 and 8. The main reasons of this problem are the big difference in elevation and pipe diameters among these zones.

5.2.3.1.2 Indicator IC_2 – distribution of water flow at different zones

Based on data of on-site experiment including duration of collecting water and water volume collected at test points, water flow at test points (column 5) is calculated equal to water volume (column 4) per duration of collecting water (column 3). Afterwards, average water flow of zones (column 6) is equal to average of water flow at test points. The indicator IC_2 (column 7) is the rate between average discharge of each zone and average discharge of system. Finally, score of each zone (column 8) is scored by comparing the values of IC_2 in column 7 with benchmark. The calculation result is shown in Table 5.36.

Table 5.36. Calculating indicator IC_2 and mark of zones

Zone	Test point	Duration of collecting water (hh:mm:ss)	Total water volume (l)	Water discharge (l/s)	Average discharge of zone (l/s)	IC_2 (%)	Mark
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
1	1	0:23:00	798	0.58	0.53	196%	4
	2	0:19:50	644	0.54			
	7	0:07:13	200.6	0.46			
2	7	0:07:13	200.6	0.46	0.34	127%	3
	8	1:27:00	2144	0.41			
	9	0:21:19	195.66	0.15			
3	9	0:21:19	195.66	0.15	0.11	41%	1
	10	1:16:00	510	0.11			
	11	2:13:00	533	0.07			
4	8	1:27:00	2144	0.41	0.21	79%	2
	9	0:21:19	195.66	0.15			
	12	0:27:29	178.06	0.11			
	13	0:20:00	210	0.17			
5	8	1:27:00	2144	0.41	0.23	86%	3
	14	0:18:43	233	0.21			
	15	0:59:00	321	0.09			
	16	0:09:54	129	0.22			
6	16	0:09:54	129	0.22	0.23	87%	3
	17	0:08:58	175.6	0.33			
	18	0:11:00	127	0.19			
	19	0:13:00	155	0.20			
7	2	0:19:50	644	0.54	0.39	145%	3
	3	0:37:00	510	0.23			
	4	0:43:00	1018	0.39			
8	3	0:37:00	510	0.23	0.15	57%	2
	6	0:42:00	194	0.08			
9	3	0:37:00	510	0.23	0.22	82%	3
	5	0:38:00	480	0.21			
	Average water flow of system				0.27		

In general, water flow of zones located at advantaged positions such as zone 1, 2 and 7 surpasses others while, in contrast, the disadvantaged zones (zone 3 and 8) have a very small amount of average water discharge. For instance, zone near pump station (zone 1) has the biggest water flow with 0.53 l/s, followed by zone 7 (little high and middle) with 0.39 l/s and zone 2 (low and middle) with 0.34 l/s. Subsequently, zones located at middle or/and far-low positions such as zone 4 (high and middle), 5 (little high and middle), 6 and 9 (far and low) have not too much different amount of average water flow that accounts for around 0.22 l/s. Finally, zone 3 and 8 located at the highest and end positions have the smallest amount of average flow with from 0.11 l/s to 0.15 l/s. Similarly, the rate between flow of each zone and average flow of system (IC_2) and its mark in benchmark have a similar tendency. Namely, IC_2 of zone 1 reachs 196% (corresponding to mark of 4) while this indicator of other zones including 2, 5, 6, and 9 fluctuates between 82% and 145% corresponding to mark of 3. Zone 4 and 8 have the value of IC_2 from 57% to 79% (corresponding to mark of 2). Finally, zone 3 has the lowest value of IC_2 with 41% corresponding to mark of 1 in benchmaking.

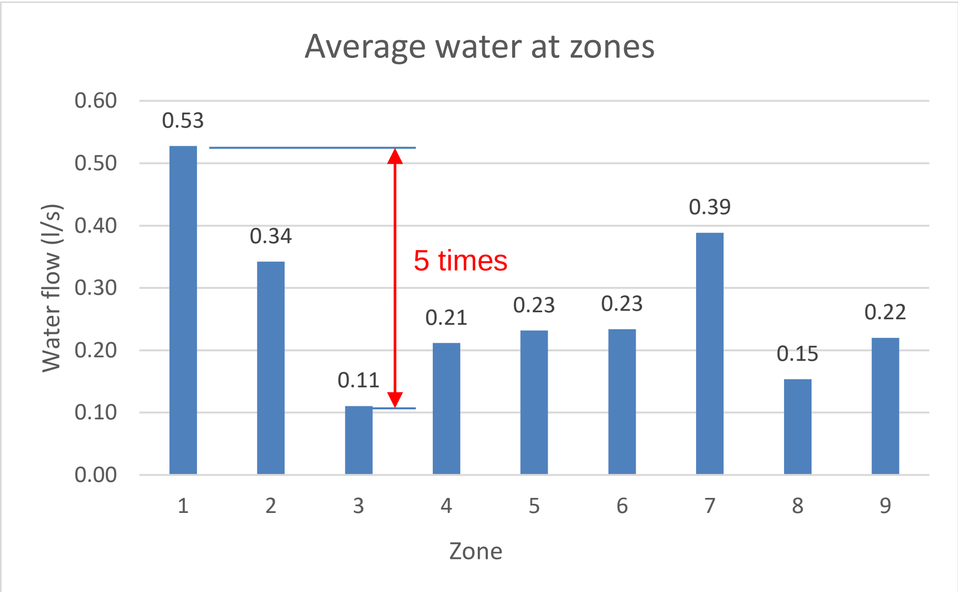


Figure 5.20. Average water flow of zones

In summary, the distribution of water flow is extreme inequality among zones in WSS. The difference in water flow distributed between the most advantaged and disadvantaged zones is up to approximately 5 times. The difference in elevation and pipe diameters among zones are main reasons lead to this problems.

5.2.3.1.3 Indicator IC_3 – the distribution of air volume

Average air volume of test points (column 2) is recorded by on-site experiment (see section 5.1.3). The number of connection (column 3) and total consumption of zones (column 5) are summarized from house-to-house investigation and data recorded by customer meters. Afterwards, total air volume of zones (column 4) is calculated equal to average of air volume of all test points in zones (column 2) multiply with number of connections of each zone (column 3). Finally, the rate of air volume and consumption of each zone (column 6) is equal to the total air volume of zones (column

6) divided by the total consumption of zones (column 5). The indicator IC_3 (column 7) is the rate of air volume and consumption of each zone with this average rate of system. Finally, score of each zone (column 8) is scored by comparing the values of IC_3 in column 7 with benchmark. The whole calculation process is shown in Table 5.37.

Table 5.37. Calculating indicator IC_3 and mark of zones

Zone	Average air volume of test points (m^3/year)	Number of connection	Total air volume of zone (m^3/year)	Consumption of zone (m^3/year)	% Air volume per consumption	IC_3 (%)	Mark
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
1	5.10	45	230	11796	2%	35%	5
2	6.41	78	500	12276	4%	74%	4
3	36.30	96	3485	24408	14%	258%	1
4	30.06	92	2766	21456	13%	233%	1
5	3.74	57	213	12276	2%	31%	5
6	11.84	165	1954	31896	6%	111%	3
7	5.25	35	184	19128	1%	17%	5
8	9.65	13	125	1884	7%	120%	3
9	3.77	56	211	18780	1%	20%	5
Average rate of air volume and consumption of system					**6%**		

A quick glance from the Table 5.37 reveals that the percentage of air volume per consumption is 6% per year on system average. The zones forced to receive the biggest air volume are zone 3 (highest and end zone) with 14% and zone 4 (high and middle zone) with 13%, followed by zone 8 (highest and end zone) where occupies around 7%. Zone 3 and 8 having the biggest percentage of air volume are suitable because such zones located at highest and end points of WSS, thus, the big amount of air will move these areas at the beginning of supplying water. However, zone 4 is one of zone receiving the biggest amount of air volume with 14% is a surprise result due to the zone located at middle position of WSS and not too much high elevation. After analysing the position of zone 4, the author recognizes that the result is suitable because this zone is local high comparing with around zones. During network fulfill process, water font will force air move to this area. Zone 1, 5, 7 and 9 have the smallest amount of air volume comparing with consumption that account for less 2%. These zones located at advantage points such as near pump station and/or low elevation. Comparing with consumption, the percentage of air volume at zone 2 is quite high with 4%. This can be explained that the zone contains local low point, thus, most air in zone 1 will move to this zone and is blocked by local low point and force air to flow though ahead connections.

In the same way, a similar trend is witnessed in the change of IC_3 through zones. Namely, the value of IC_3 is biggest at zone 3 and zone 4 with 258% and 233%, respectively (corresponding to mark of 1 in benchmark), followed by zone 6 and zone 8 with 111% and 120% (equivalent to mark of 3 in benchmark). Zone 2 having the value of IC_3 is 74% corresponding to mark of 4 in benchmark. The remaining zones including zone 1, 5, 7, and 9 have the value of IC_3 from 17% to 35% (corresponding to mark of 5 in benchmark.

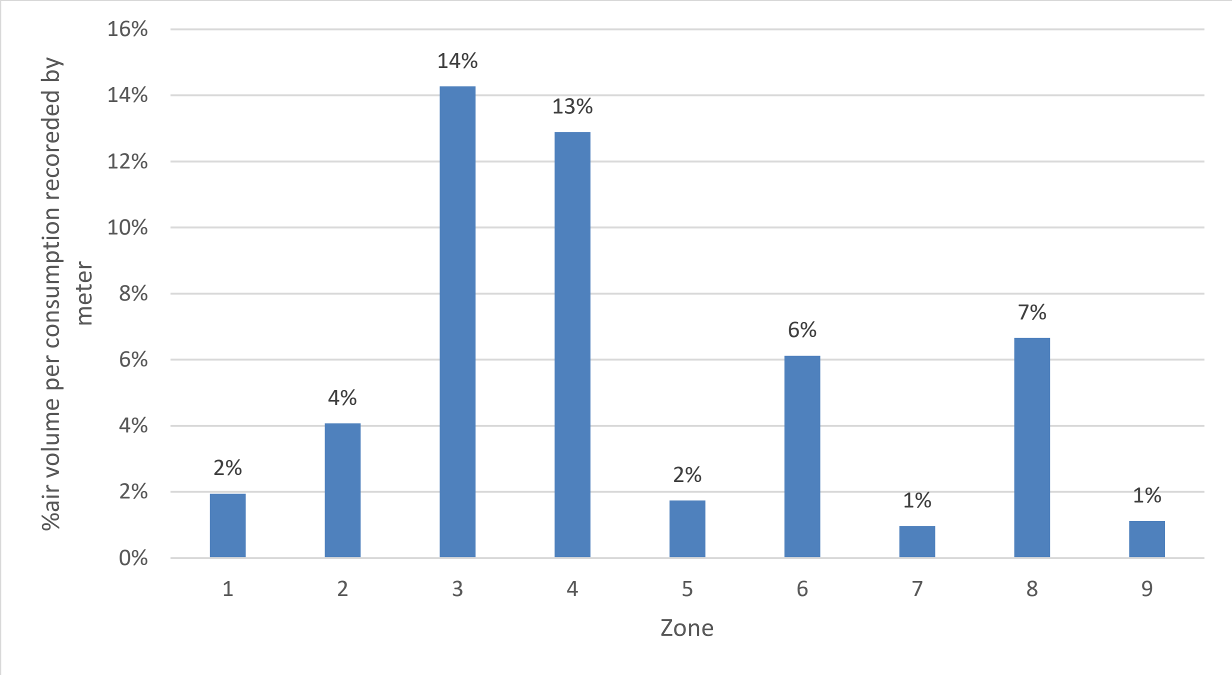


Figure 5.21. The distribution of air volume at different zones

In summary, comparing the percentage between air volume and consumption at different zones in WSS shows that zone located at highest and end positions (zone 3 and 8), or local high positions such as zone 4 will be forced to receive the biggest amount of air volume that is up to 14%. In contrast, zones having smallest percentage of air volume belong to areas where near pump station and/or low position.

5.2.3.1.4 Indicator IC_{41} and IC_{42} – the rate of households connecting with WSS

Due to inequality of distribution in WSS, customers located at disadvantaged points have to find out their solutions to have enough water to use for whole year. One of the common solutions in Dong Van city is diversity of water supply sources such as rainfall, water from cliffs or drilled well. Analysing data of house-to-house investigation, the data including total households (column 4), number of households connecting with WSS (column 2), and number of households connecting with WSS and only using water from WSS (column 3) are identified in Table 5.38. The percentage of households connecting with WSS (column 5) is calculated equal to column 2 divided by column 4 while the percentage of households only using water from WSS (column 6) equal to column 3 divided by column 4. The indicators IC_{41} and IC_{42} are calculated by the percentage of each zone in column 7 and 9 divided by the average percentage of system. The mark of each zone (column 8 and 10) is identified by comparing the value of IC_{41} and IC_{42} of each zone with the benchmark.

Table 5.38. Calculating indicator IC_4 and mark of zones

Zone	Households			% households		IC_{41} (%)	Mark	IC_{42} (%)	Mark
	connect WSS	only use water from WSS	total	connect with WSS per total households	only using water from WSS per total households				
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*
1	45	40	57	79%	70%	110%	3	138%	3
2	78	58	83	94%	70%	131%	3	137%	3
3	96	51	212	45%	24%	63%	2	47%	1
4	92	42	139	66%	30%	92%	3	59%	2
5	57	25	117	49%	21%	68%	2	42%	1
6	165	128	197	84%	65%	116%	3	128%	3
7	35	35	35	100%	100%	139%	3	197%	4
8	13	3	26	50%	12%	69%	2	23%	1
9	56	45	69	81%	65%	113%	3	128%	3
Average of system				**72%**	**51%**				

None: Households connecting with WSS can use both water from WSS and other sources at the same time or only water from WSS or only water from other sources. Households only using water from WSS mean that these households using 100% water from WSS.

It is quite surprise that 100% households in zone 7 (quite high and central zone) connect and use water from WSS although this area is not the most advantaged zone. However, analysing data reveals that this area is home of many government offices, big hotels and restaurants where have big budget to build enough volume of private tanks to store water for many days. Afterwards, zone 2 (low and middle zone) with 94% households of connect with WSS, but only 70% households completely use water from WSS. Many households in this area also use water from other sources such as water from cliffs or drilled well. Zone 1 having the rate of households connecting with WSS is not too much high with 79% (only 70% households use completely water from WSS) although this zone is near pump station. It can be explained that this area is very near supply source (water cliffs supply for pump station), thus, many households use their pipes to collect water for themselves. More 80% households of zone 9 and 6 connect with WSS but only 65% households using completely from WSS. This rate is quite high comparing with around zones because these zones located at low points in WSS. Next, zone 4 and zone 5 have the quite small percentage of households connecting with WSS that account for 66% and 49% respectively though such zones are located at central points in WSS. Analysing data of house-to-house investigation and maps points out that these areas are quite high in comparison with others. Customers living at these zones supplement water from other sources such as water from cliffs or/and drilled wells. Finally, two zones located at the most disadvantaged points – highest and end positions (zone 3 and 8) have smallest percentage of households connecting with WSS. Namely, only 45% households in zone 3 connecting with WSS (24% of them using 100% water from WSS) while this rate in zone 8 is 50% (only 12% of them using 100% from WSS). The majority of citizens in the areas have to look for other water sources instead of water from WSS such as water from cliffs and drilled wells.

The score of IC_{41} changes not too much in different zones (from 2 to 3) while the score of IC_{42} has the bigger change from 1 to 4 in benchmark. For instance, some zones such as zone 1, 2, 4, 6, 7, and 9 where the value of IC_{41} fluctuates from 92% to 139% have the same value of score of 3 in benchmark whilst the remaining zones including zone 3, 5, and 8 with the value of IC_{41} from 63% to 69% have the same level of score of 2 in the benchmark. On the other hand, zone 4 has the biggest value of IC_{42} with 197% (equivalent to mark of 4), followed zone 1, 2, 6, and 9 where the value of IC_{42} go up and down from 128% to 138% (equivalent to mark of 3). Afterwards, with the value of IC_{42} about 59%, zone 4 is classified in level 2 of benchmark. Finally, zone 3 and 8 has the smallest value IC_{42} with 47% and 23% (corresponding to mark of 1).

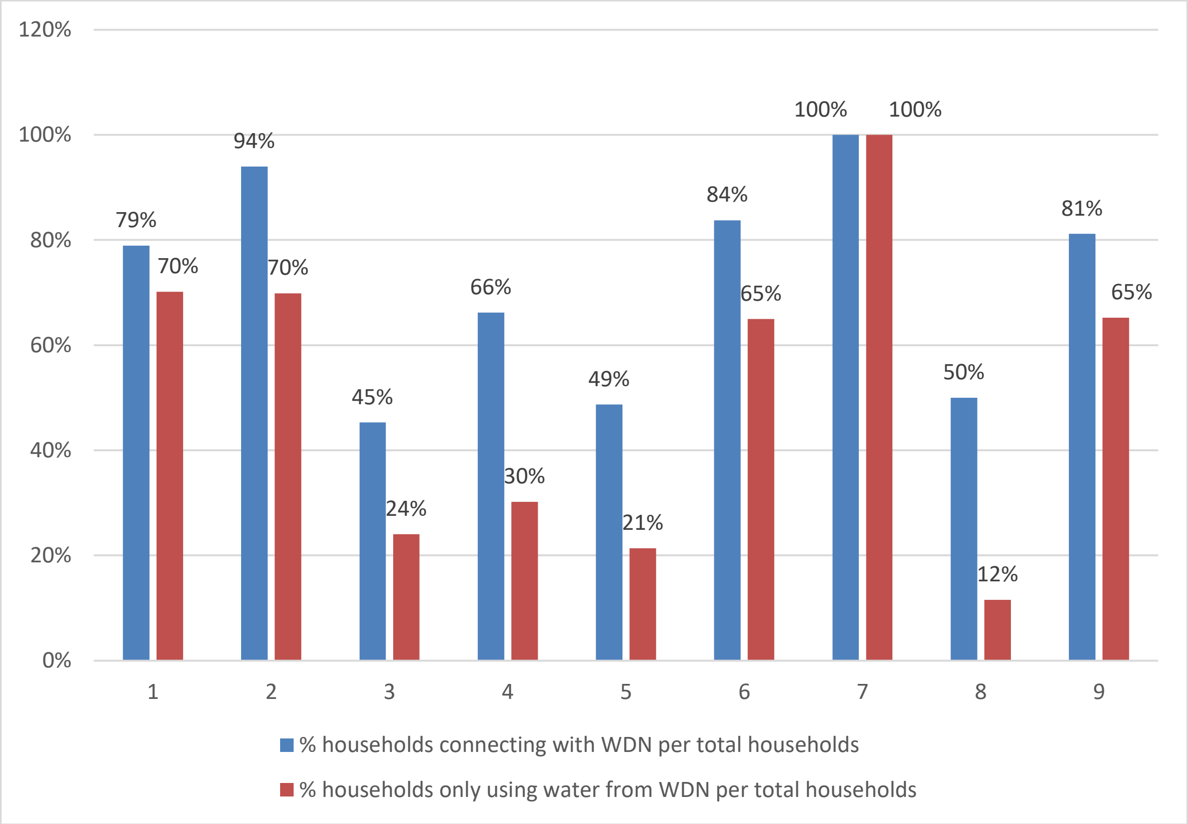


Figure 5.22. The rate of households using water from WDN at various zones

In summary, water from WSS is not enough to supply for all zones over year, except zone 7. Customers have to use different sources including water from cliffs, drilled wells, and rainfall. Zone 7, 2, 9, and 1 have the biggest percentage of household using water from WSS while household located at disadvantaged points such as zone 3 and 8 have the very small rate of using water from WSS.

5.2.3.1.5 Indicator IC_{51} and IC_{52} – The level of water consumption at different zones

From data of water consumption recorded by customer meters and house-to-house investigation, the level of water consumption at various zones is calculated in Table 5.39. Namely, real consumption (column 3) is equal to consumption recorded by customer meters (column 2) minus total air volume forced to receive. Then, column 4 and 7 are calculated by the value of column 2 and 3 divided by the number of people in each zone. The indicators IC_{51} and IC_{52} are the rate between consumption of each zone and average consumption of system. Mark of each zone (column 5 and 8) is identified by comparing the value of IC_{51} and IC_{52} with the benchmark.

Table 5.39. Calculating indicator IC_5 and mark of zones

Zone	Consumption recorded by meter (m^3/year)	Real consumption (m^3/year)	Consumption recorded by meter (l/ca/day)	IC_{51} (%)	Mark	Real consumption (l/ca/day)	IC_{52} (%)	Mark
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*
1	11796	11567	113	112%	3	111	114%	3
2	12276	11776	81	80%	2	78	80%	2
3	24408	20924	63	62%	2	54	56%	2
4	21456	18691	85	83%	3	74	76%	2
5	12276	12062	57	57%	2	56	58%	2
6	31896	29943	89	87%	3	83	86%	3
7	19128	18944	299	295%	5	297	305%	5
8	1884	1759	40	39%	1	37	38%	1
9	18780	18569	86	85%	3	85	87%	3
Average of system			**101**			**97**		

A quick glance from the result shows that the consumption level with 299 l/day/capita in zone 7 – little high and middle zone is much bigger than others. This can be explained that this zone is home of some big hotels such as Hoa Cuong hotel and restaurant (biggest one in Dong Van city). Afterwards, consumption in zone 1 (near pump station) is 113 l/day/capita, followed by zone 2 (low and middle zone), zone 4 (high and middle zone), zone 6 (low and end zone), and zone 9 (low and end zone) that account for around 80 l/day/capita. Though zone 5 located at central area in WSS, the water consumption is quite low with 57 l/day/capita. The water consumption in zone 5 is low because the number of households using 100% water from WSS only accounts for less 50% in total households connecting with WSS. Finally, two zones (3 and 8) located at the most disadvantaged points in WSS (highest and end zone) have the smallest amount of water consumption that accounts for 55 and 38 l/day/capita, respectively. Besides, the Figure 5.23 shows that customers in zone 3 and 4 have to pay about 10 l/day/capita in extra because of air volume. The remaining zones pay averagely around 3 l/day/capita of air volume.

Similarly, the rate between consumption of each zone and average consumption of system (IC_{51} and IC_{52}) witnesses a similar tendency. For instance, consumption level of zone 7 is around three times bigger (IC_{51} is 295% and IC_{52} is 305%) than average consumption of system, which is classified in level of 5 in benchmark. IC_{51} and IC_{52} of some zones such as zone 1, 6, and 9 have the value from 85% to 114% equivalent to mark of 3 in benchmark, followed by zones comprising zone 2, 3, and 5 with the value from 57% to 83% equivalent to mark of 2 in benchmark. The value of IC_{51} and IC_{52} in zone 8 is smallest with 39% and 37% (equivalent to mark of 1 in benchmark), respectively.

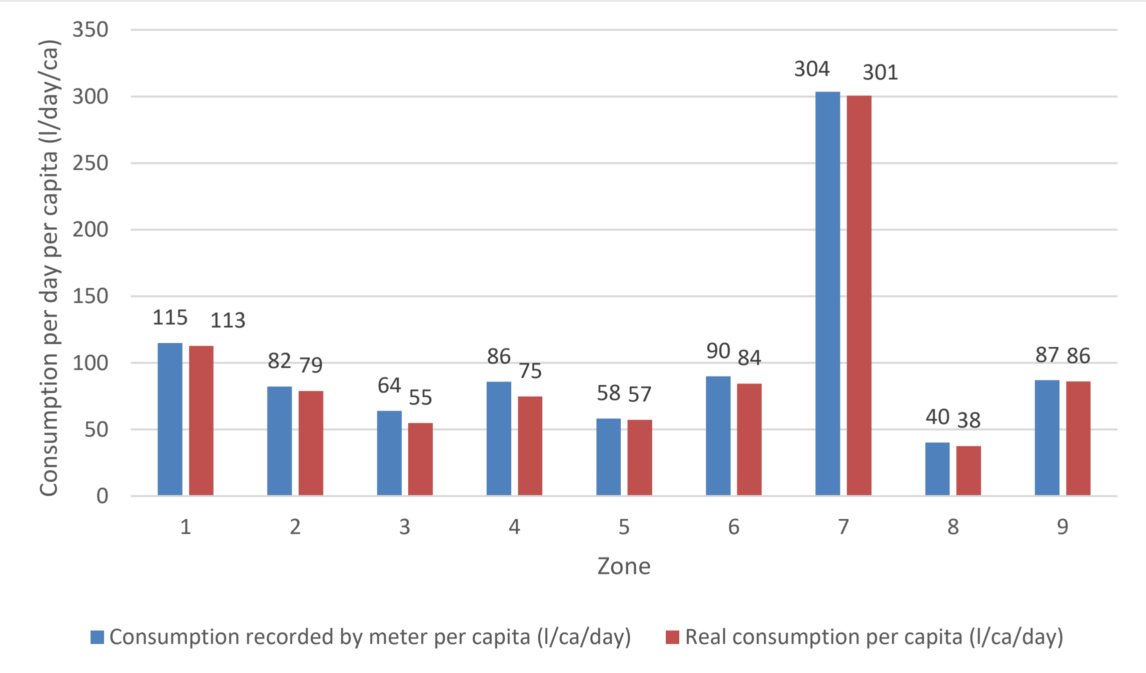


Figure 5.23. The level of average consumption at zones

In summary, households located at disadvantaged points have to use many different sources of water, thus they often have smaller amount of water in consumption level than other areas. Comparing with the national standard of domestic water supply (from 80 to 150 l/day/capita), there are some zones meet the demand comprising zone 7, zone 1, zone 6, and zone 9.

5.2.3.1.6 Indicator IC_6 – Volume of private tank at different zones

In intermittent water supply system, private tanks are indispensable to store enough water for whole day. Logically, households located at disadvantaged points will have to build bigger tanks than others. From data of house-to-house investigation, total number of households connecting with WSS and total volume of private tank are defined in column 2 and 3 of Table 5.40. The rate of tank volume and household (column 4) is equal to column 3 divided by column 2. Next, the indicator IC_6 (column 5) is the rate between tank volume per household of each zone and tank volume per household of system. The mark of each zone (column 6) is identified by comparing the value of IC_6 with the benchmark.

Two zones located at the most disadvantaged points in WSS (zone 3 and 8) have the biggest volume of private tanks in average with 9.1 and 10.5 m^3/household respectively, followed by zone 9 – low and end zone with 6.7 m^3/household. The average volume of private tank in zone 1, zone 4, zone 5, and zone 6 is from 5.0 to 5.5 m^3/household. Finally, two zones have the smallest volume of private tank in average are zone 2 and zone 7 with 3.7 and 3.1 m^3/household, respectively.

Table 5.40. Calculating indicator IC_6 and mark of zones

Zone	Total number of households connecting WDN (household)	Total volume of private tank (m^3)	The rate of tank volume per household (m^3/household)	IC_6 (%)	Mark
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
1	45	224	5.0	68%	3.0
2	78	287	3.7	51%	4.0
3	96	869	9.1	124%	2.0
4	92	488	5.3	73%	3.0
5	57	313	5.5	75%	3.0
6	165	871	5.3	72%	3.0
7	35	512	14.6	201%	1.0
8	13	136	10.5	144%	2.0
9	56	375	6.7	92%	3.0
	Average tank volume of system		**7.3**		

It is surprise that zone 7 have the biggest value of IC_6 because this zone is located at quite advantaged position in WSS. This can be explained that this zone is home of many big governmental utilities including People's Council – Committee, Dong Van district Committee, High School, Secondary school, especially Hoa Cuong hotel. This hotel is the biggest in Dong Van city using 100% water from WDN with 81 rooms. There are 20 stainless steel roof tanks (3m^3/1 tank), 1 cistern tank - 270m^3, and 1 cistern tank – 75 m^3 for reservation in this hotel. Afterwards, zone 3 and zone 8 have the value of IC_6 from 124% to 144% equivalent to mark of 2 in benchmark, followed by zones such as zone 1, 4, 5, 6, and 9 with the value of IC_6 from 68% to 92% equivalent to mark of 3 in benchmark. Finally, zone 2 has the smallest value of IC_6 with 51% equivalent to mark of 4 in benchmark.

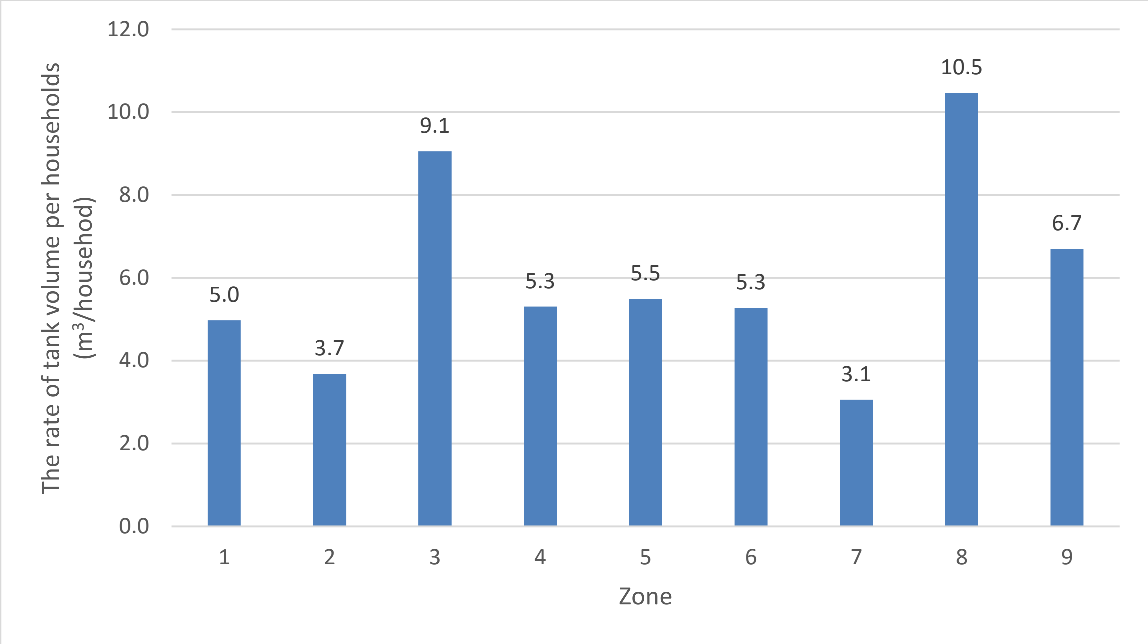


Figure 5.24. Average volume of private tank at zones

In brief, households located at the highest and end points such as zone 3 and 8 have to build three times bigger volume of private tank than households at advantaged ones to store enough water for whole day.

5.2.3.1.7 Evaluate inequality of distribution at different zones

In order to evaluate inequality of distribution of WSS in Dong Van city, WSS is broken into 9 different zones such as near pump station (zone 1), low and middle zone (zone 2), little high and middle zone (zone 5 and 7), high and middle zone (zone 4), low and end zone (zone 6 and 9), and highest and end zone (zone 3 and 8) based on elevation and pipe diameters.

The inequality of distribution impacts on different zones in some aspects such as distribution time, water flow, and air volume. Water users, to adapt to the inequality, have to look for solutions themselves to have enough water. There are some common solutions such as using many water sources at the same time (from WDN, water cliffs, drilled well, rainfall), building bigger private tank, or using water saver than other zones. As the result, the rate of water users connecting with WSS, level of consumption, and volume of private tanks will be different among zones in distribution network.

The indicators of inequitable distribution including eight indicators IC_1, IC_2, IC_3, IC_{41}, IC_{42}, IC_{51}, IC_{52}, and IC_6 will comprehensively evaluate the inequality of system from distribution network to customers. Namely, IC_1, IC_2, and IC_3 will evaluate the inequality of distribution network (time, water flow, and air volume) while IC_{41}, IC_{42}, IC_{51}, IC_{52}, and IC_6 will assess customer's solutions to have enough water over year (rate of customers connecting with WSS, consumption level, and volume of private tank).

By using the method of observing customer meters, the inequality of distribution in WSS can be identified quickly. The inequality of distribution of WSS at different zones is summarized in Table 5.41. In this table, the average mark of zone is calculated follow equation 4.7.

Table 5.41. The inequality of distribution at different zones

Zone	IC_1	IC_2	IC_3	IC_{41}	IC_{42}	IC_{51}	IC_{52}	IC_6	**Average mark of zone**	Maximum difference among zones	Classification
1	5	4	5	3	3	3	3	3	**4.3**	**3.1**	**Very bad**
2	5	3	4	3	3	2	2	4	**3.7**		
3	1	1	1	2	1	2	2	2	**1.2**		
4	5	2	1	3	2	3	2	3	**2.7**		
5	5	3	5	2	1	2	2	3	**3.8**		
6	5	3	3	3	3	3	3	3	**3.5**		
7	5	3	5	3	4	5	5	1	**4.2**		
8	1	2	3	2	1	1	1	2	**1.9**		
9	5	3	5	3	3	3	3	3	**4.0**		

Table 5.41 reveals that maximum difference among zones is 3.1 (zone 1 and zone 3). It means that the inequality of distribution is very bad among zones in distribution network.

Zone 1 (near pump station) is located at the most advantage position in WSS. Thanks to this, zone 1 take all advantages in distribution process such as the longest time of available water at all connections (approximately supply time of service), the biggest of water flow (0.53 l/s), small amount of air volume comparing with consumption (2%). However, zone 1 having the rate of households connecting with WSS is not too much high with 79% (only 70% households use completely water from WSS) because this area is very near supply source (water cliffs supply for pump station), thus, many households use their pipes to collect water for themselves. Besides, level of consumption is quite high with 111 l/s (only behind zone 7) and volume of private tank is smaller than other zones. As the result, almost of all indicators of zone 1 are classified in highest level of benchmark, which leads to highest average mark of this zone in WSS (4.3).

Zone 2 is located at low and middle position of distribution network (quite near pump station). Hence, similar to zone 1, most indicators of zone 2 are classified in high level of benchmark, which leads to high average mark of this zone in WSS (3.7).

Zone 3 and zone 8 are located at end and highest position of pipeline network. Thus, all disadvantaged factors belongs to this zone. Namely, available water for all connections of two zones about 1 hour per day, the lowest water flow (around 50% comparing average flow of system), and the biggest air volume forced to receive (258% at zone 3 and 120% at zone 8 comparing with average volume of system). Due to this, only 24% households of zone 3 (around 47% comparing with average rate of system) and 12% households of zone 8 using 100% from WSS (around 23% comparing with average rate of system). The consumption level of these two zones is also two of zones having the smallest consumption (56% of zone 3 and 38% of zone 8 comparing with average consumption of system). Besides, in order to adapt to this bad condition, average volume of private tank in these two zones is also two of zones with the biggest volume of tanks. As a result, most indicators of zone 3 and 8 are classified in the lowest level of benchmark (mark of 1). Logically, average mark of these two zones is the lowest in WSS with 1.2 of zone 3 and 1.9 of zone 8.

Although zone 4 is located at central position of WSS, its position is local high comparing around zones. Hence, zone 4 suffers many negative factors such as low water flow (79% comparing with average flow of system), high air volume (233% comparing with average flow of system). In addition, the rate of households connecting with WSS (66% comparing with average rate of system) and consumption level (76% comparing with average rate of system) are quite low in this zone. Consequently, most indicators of zone 4 are evaluated in quite low level of benchmark, which leads to average mark of zone 4 is only 2.7.

Similar to zone 4, zone 5 is also located at middle position of WSS, but average elevation of this zone is lower than elevation of zone 4. Hence, two important indicators of this zone (IC_2 and IC_3) are much better than two indicators of zone 4. For instance, IC_2 (water flow) reaches 86% comparing with average flow of system (equivalent to mark of 3 in benchmark) while IC_3 (air volume) is only 31% comparing with average rate of system (equivalent to mark of 5 in benchmark). Thanks to this, the average mark of zone 5 reaches 3.8 (higher than average mark of system).

Though zone 6 and 9 are located at end position of WSS, they are two of lowest areas in WSS. Thus, most the mark of indicators of these two zones is quite high and the same level, except indicator IC_3. Namely, the mark of indicator IC_1 (available time of water) is 5 while IC_2 (water flow), IC_{41} (rate of households connecting with WSS), IC_{42} (rate of households using 100% water from WSS), IC_{51} (level of water consumption recorded by meter), IC_{52} (level of real consumption), IC_6 (volume of private tank) all have the mark of 3 in benchmark in both of two zones. Therefore, the average mark of zone 6 and 9 is not too much different (mark of zone 6 is 3.5 whilst mark of zone 9 is 4.0).

Zone 7 is located at central position of WSS, but its elevation is a bit higher than surroundings. Many indicators of this zone have the high level of mark in benchmark such as available time of water (99% comparing with supply time of service), water flow (145% comparing with average flow of system), air volume (17% comparing with average air volume of system), the rate of households connecting with WSS (100%), level of consumption (305% comparing with average consumption of system). Thanks to this, the average mark of this zone is very high (4.2) that is only a bit smaller than mark of zone 1 (4.3).

5.2.3.2 Water quality

Most pipelines are located underground and near sewage ditch. Thus, contaminated water and soil particles from the surrounding soil will infiltrate the pipelines through leak openings during the time of without supplying water of service. Then, when water is supplied again, water running through the pipe network and the dirty water ahead of the arrival of the water happens always at the beginning of the network filling process. Afterwards, water quality in WSS will be getting better and stable after all these contaminated water going inside households. This dirty water front is discharged through water meters of customers and goes in private tanks. Besides, the present of private tanks inside households also have both positive and negative effects on water quality. For instance, roof tanks because of being located at the top of houses often rise water temperature, which can make a better environment for proliferating bacteria. However, roof tanks are also a good environment to deposit dirt and impurities if the tanks are cleaned regularly.

Therefore, in the first time, the test result before private tank (as soon as water reaching to customer meters) shows water quality of stagnation water while the test after private tank is water quality of private tank during the time of without supplying water. The second time (after 5 hours of pumping water) will check water quality in operation condition of service. Namely, water samples before private tanks will reflect the influence of pipeline on water quality, and water samples before private tanks will provide information about water quality in combination of water from WSS and stagnation water (both from private tanks themselves and from pipeline network).

Due to the limitation of time and budget, there are five parameters tested in this research including total coliforms, E. coli, turbidity, electrical conductivity (EC), and pH to evaluate the impact of intermittent supply and private tank on water quality.

5.2.3.2.1 Total coliforms

Due to the limitation of samples number, total coliforms and E. coli samples were only taken at five points (see Figure 5.25) comprising pump station and end points of pipeline network (from 2 to 5). These samples will provide a general picture of changing total coliforms and E. coli in WSS.

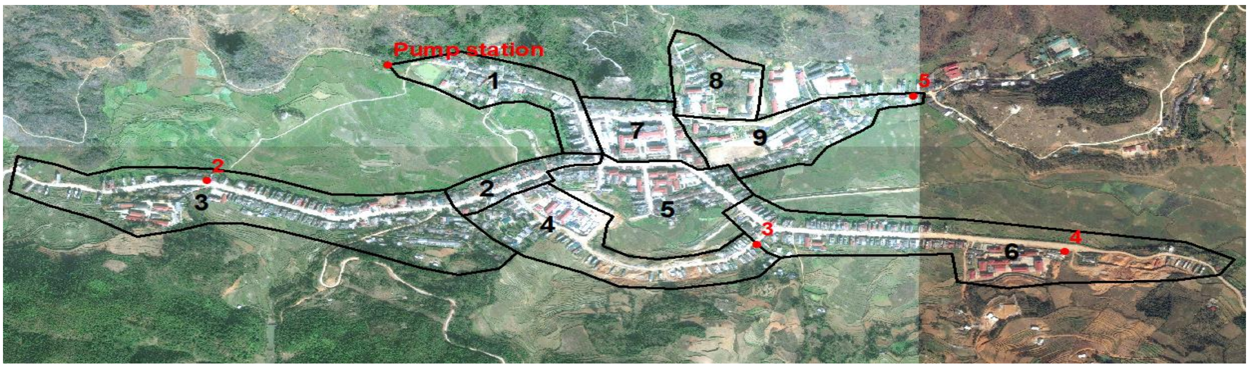


Figure 5.25. Positions of taking total coliforms and E. coli samples (red colors) in different zones (black colors)

A quick glance from Figure 5.26 and Table 5.42 shows that total coliforms witness a significant increase at all end points of WSS, especially at position 5 where rockets over 30 times in maximum comparing with pump station. The number of coliforms before private tanks at the beginning of supplying water again (blue line) surpasses others. Afterwards, this number decreases at all positions during the time of operation of service, but still much bigger that itself at pump station.

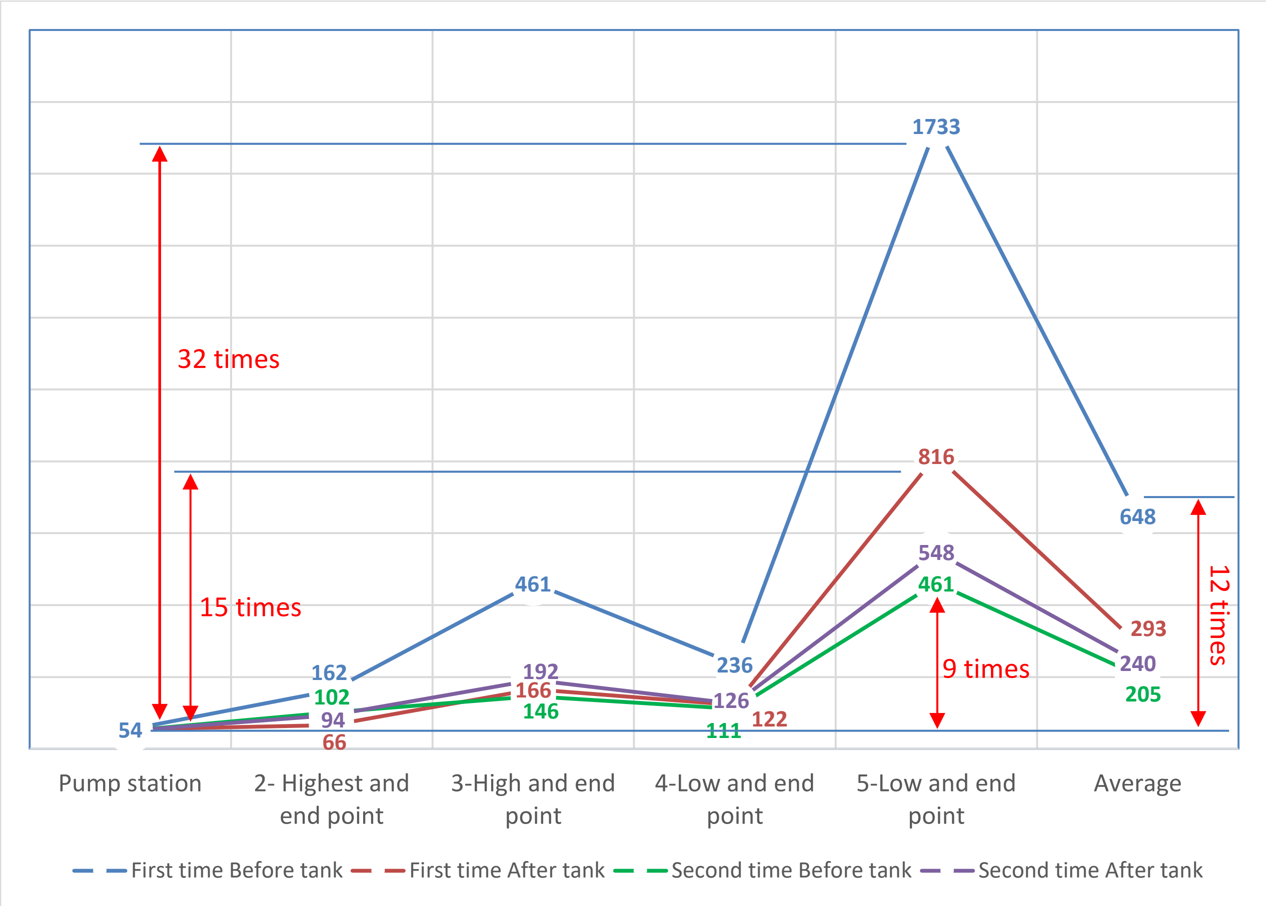


Figure 5.26. The change of total coliforms in pipeline network

In the first time of test – as soon as water coming to household (blue line), although the number of total coliforms is solely 54 MPN/100ml at the supply source, the number goes up many times at the end points of pipeline network such as 32 times at point 5 (low and end point), 4 times at point 4 (low and end point), 9 times at point 3 (high and end point), 3 times at point 2 (highest and end point), and 12 times in average at end points. The number of total coliforms is very big at the end points because, in fact, most water is stagnation water during the time of without supplying water. On the other hand, the test result after private tank (red line) shows the number of total coliforms at private tanks during the night time. These figures are also many times bigger than themselves at pump station. For example, the test sample at point 5 has the biggest number of total coliforms that accounts for 816 MPN/100ml (15 times), followed by point 3 with 166 MPN/100ml, point 2 (122 MPN/100ml), and point 2 (66 MPN/100ml). The number of coliforms at private tanks during the night time is 5 times bigger than its number at supply source on average.

In the second time of test – after 5 hours of supplying water, the number of total coliforms depends on water quality of supply source, the cleanliness level of pipes, and the interaction of water inside pipes and surroundings through leakages. The test result reveals that the number of total coliform (green line) is different at points, but still much bigger than its number at pump station. Namely, the test point 5 still has the biggest number of coliforms with 461 MPN/100ml (9 times), followed by 146 MPN/100ml at point 3 (3 times), and 102 MPN/100ml at point 2 (2 times). The number of coliforms at end points in WSS is 4 times bigger than its number at source on average. On the other side, water inside private tanks at this time is mixed by new water from system, water available in the tank from last day, and stagnation water of pipeline network during the time of without supplying water. The test result (purple line) show that the number of total coliforms is also much higher than itself at source (5 times on average). The point 5 always have the biggest number of coliforms with 548 MPN/100ml (11 times) whilst these figures at the remaining points are between 94 and 192 MPN/100ml.

Table 5.42. Calculating indicator IC_7 – total coliform

No.	Indicator \ Zone	3	4	6	9	**Average**	Weight
	Change of total coliform in pipeline network						
IC_{71}	The rate of total coliform as soon as water coming to test points and total coliform at supply source (times)	3.0	8.5	4.4	32.1	**12.0**	3
IC_{72}	The rate of total coliform at test points in running time of service and total coliform at supply source (times)	2.0	2.9	2.2	9.0	**4.0**	3
	Change of total coliform before and after private tank						
IC_{73}	The rate of total coliform after and before private tanks as soon as water coming to private tanks (times)	0.4	0.4	0.5	0.5	**0.4**	1
IC_{74}	The rate of total coliform after and before private tanks in running time of service (times)	0.9	1.3	1.1	1.2	**1.1**	1
	Average total coliform of zones	**2.0**	**4.5**	**2.7**	**15.6**	**6.2**	

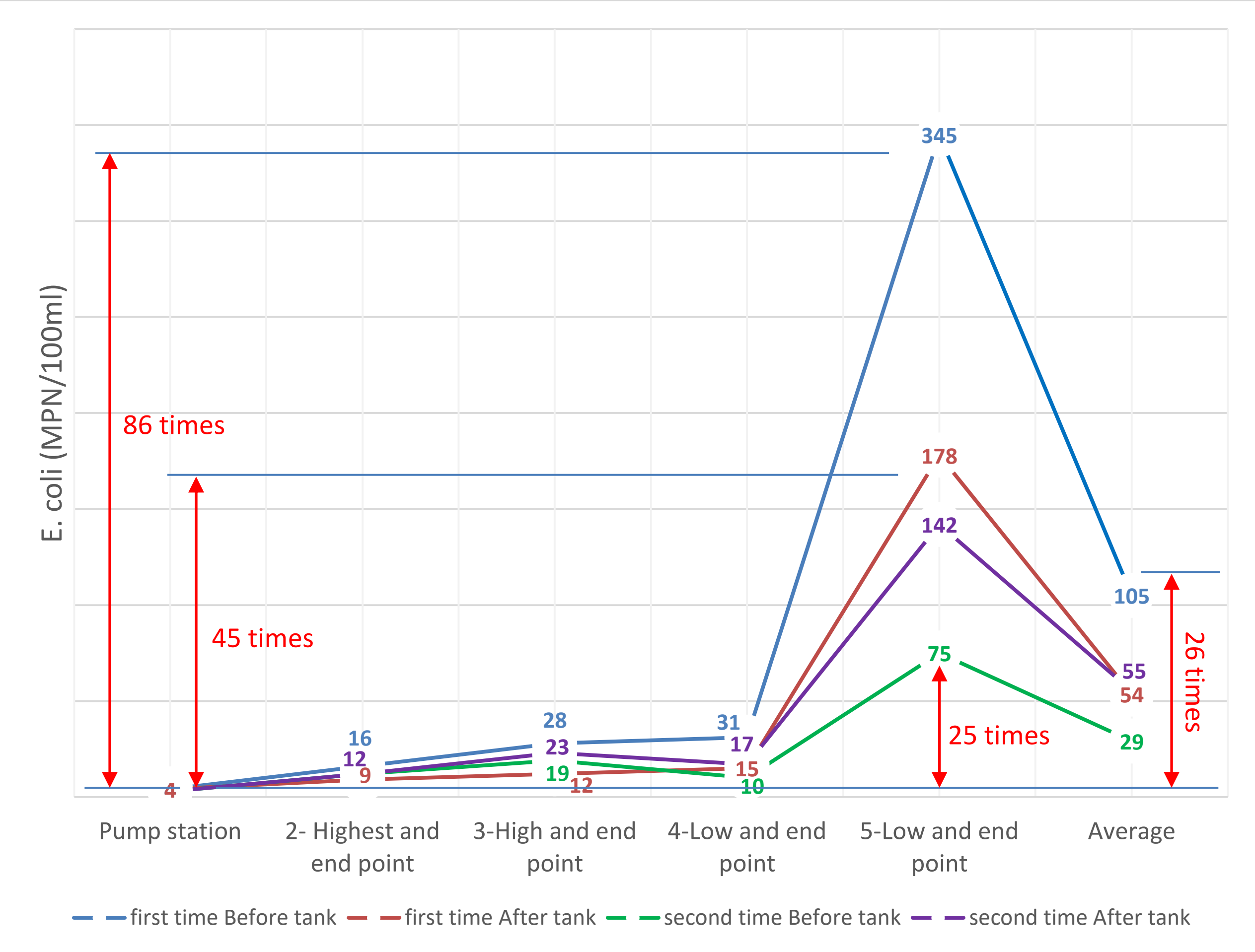
In brief, on average, the number of total coliform of stagnation water (IC_{71}) inside pipeline network during the time of without supplying water is 12 times bigger than this parameter at supply source. After all these dirty water going into private tanks, the water quality inside distribution system is getting better. However, the average number of total coliform (IC_{72}) at end points of WSS is still around 4 times higher comparing number of total coliform at supply source. On the other hand, the stagnation water is also a potential dirty source that contaminates private tanks. IC_{73} proves that total coliform of stagnation water is over twice bigger than total coliform of water inside private tank at the time stagnation water coming to private tank on average. Then, water of private tanks is mixed by remaining water of private tank from last day, stagnation water of WSS, and new water from supply source. Hence, total coliform of water inside private tank (IC_{74}) is a little higher (1.1

times) than total coliform of new water from supply source. Finally, due to intermittent water supply, leakages on distribution system, and private tank, the number of total coliform at customer tap of end points in WSS (IC_7) is 6.2 times higher than this parameter at supply source on average.

Comparing between zones, zone 9 has the biggest number of total coliform with 15.6 times bigger, followed by zone 4 (4.5 times), zone 6 (2.7 times), and zone 3 (2 times). It can be estimated that the pipes in zone 9 have more leakages than others or surroundings of pipes in zone 9 contain contaminated sources.

5.2.3.2.2 E. coli

In general, although there is different about value at test points, the change of E. coli in pipeline network has the similar trend with total coliforms. It means that the number of E. coli in WSS as soon as water coming to household at the first time is much bigger than itself at other times. Besides, the value of E. coli at test point 5 also surpasses other points.



In the first time, the result of analysing water samples taken as soon as water coming households before private tank (blue line) show that the number of E. coli at test point 5 has the biggest value with 345 MPN/100ml (86 times bigger than itself at supply source), followed by test point 4 with 31 MPN/100ml (8 times), test point 3 with 28 MPN/100ml (7 times), and test point 2 with 16 MPN/100ml

(4 times). In average, this number at end points of WSS is 26 times bigger than itself at pump station. On the other hand, the number of E.coli at private tank is smaller than the number of E. coli of stagnation water inside pipe during the time of without supplying water, but still much bigger than its value at pump station. For example, the value of E. coli is in the order: biggest at test point 5 with 178 MPN/100ml, next to test point 4 with 15 MPN/100ml, and then test point 3 with 12 MPN/100ml, and test point 2 with 9 MPN/100ml.

After all stagnation water inside pipeline network go in private tank, water quality is getting better and stable. Thus, the number of E. coli (green line) after 5 hours of supplying water is smaller than itself at the beginning of running service, but still much bigger than at supply source. Namely, the number of E. coli goes up approximately 10 times in average, and maximum 25 times at test point 5. Similarly, the number of E. coli at private tank at this time (purple line) increase 18 times in average and maximum 47 times at test point 5 comparing with the E. coli number at Lang Nghien pump station.

Table 5.43. Calculating indicator IC_8 – E. coli

No.	Indicator / Zone	3	4	6	9	**Average**	Weight
	Change of E. coli in pipeline network						
IC_{81}	The rate of E. coli as soon as water coming to test points and E. coli at supply source (times)	4.0	7.0	7.8	86.3	**26.3**	3
IC_{82}	The rate of E. coli at test points in running time of service and E. coli at supply source (times)	4.0	6.3	3.3	25.0	**9.7**	3
	Change of E. coli before and after private tank						
IC_{83}	The rate of E. coli after and before private tanks as soon as water coming to private tanks (times)	0.6	0.4	0.5	0.5	**0.5**	1
IC_{84}	The rate of E. coli after and before private tanks in running time of service (times)	1.0	1.2	1.7	1.9	**1.5**	1
	Average E. coli of zones	**3.2**	**5.2**	**4.4**	**42.0**	**13.7**	

In brief, on average, stagnation water inside pipeline network at end points of distribution system (IC_{81}) has the number of E. coli around 26 times comparing number of E. coli at supply source while the rate between E. coli at test points and E. coli at supply source (IC_{82}) is approximately tenfold during the operation time of service. On the other hand, E. coli of stagnation water is twice comparing with E. coli of remaining water of private tank from last day (IC_{83}) on average. Then, water inside private tanks is combined by remaining water of private tank from last day, stagnation water of distribution system, and new water from supply source. Hence, IC_{84} (rate of E. coli after and before private tanks in running time of service) at this time is about 1.5 times on average. Comparing among different zones, zone 9 has the biggest number of E.coli comparing with supply source with 42 times bigger, followed by zone 4 (5.2 times), zone 6 (4.4 times), and zone 3 (3.2

times). The indicator of E. coli (IC_8) reveals that the value of IC_8 surpass many times than other. Thus, it can be estimated that the pipes in zone 9 have more leakages than others or surroundings of pipes in zone 9 contain contaminated sources.

5.2.3.2.3 Turbidity

To check the change of turbidity, electrical conductivity (EC) and pH, there are specific 17 points selected (see Figure 5.27) including pump station, end points of WSS, points of changing elevation and/or pipe diameter and/or direction, and points at the beginning of branch pipes.

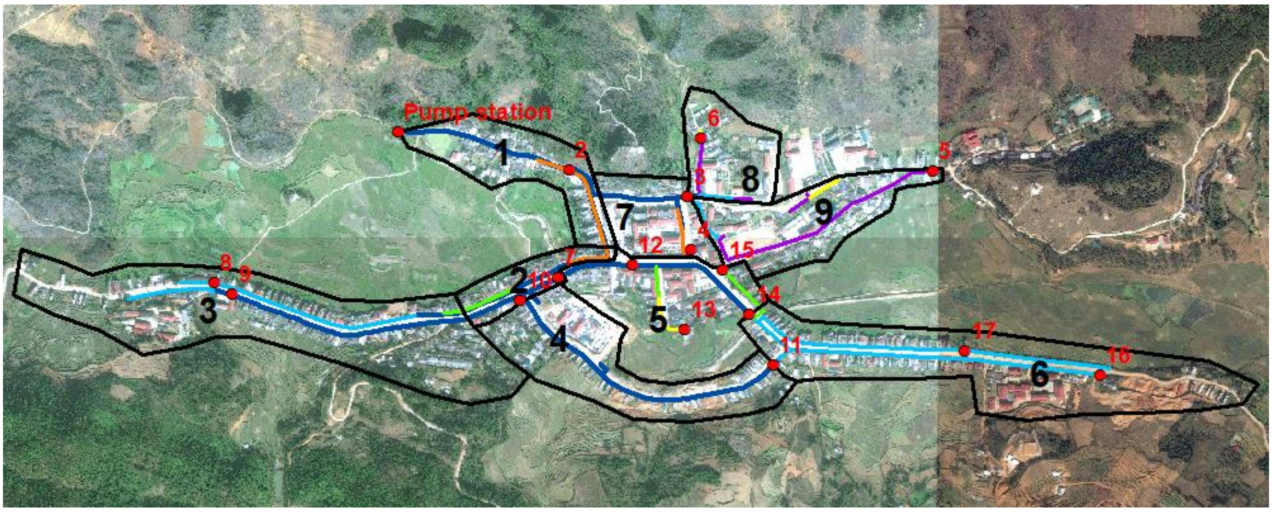


Figure 5.27. Positions to check turbidity, EC, and pH (red color) in different zones (black color)

In general, the turbidity witnesses the different change among positions, but low zones such as zone 6 and zon9 often have bigger turbidity than others, especially at the first time. It can be explained that stagnation water inside pipeline network flows to low areas during the time of without supplying water.

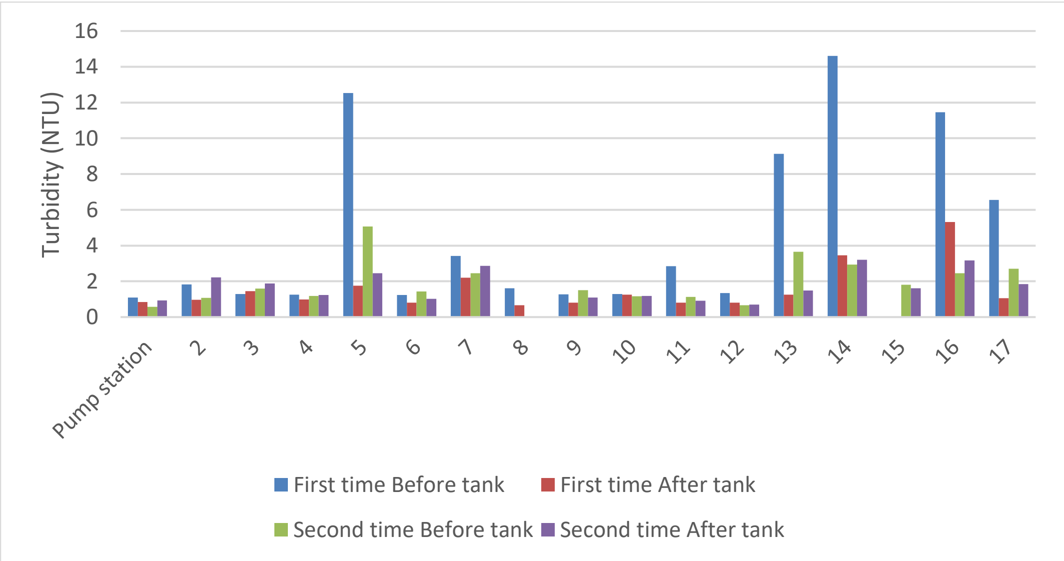


Figure 5.28. The change of turbidity in pipeline network

In the first time – as soon as water coming to household (blue color), the turbidity in average in pipeline network is 5 times bigger than itself at supply source. Some test points such as 2, 3, 4, 6, 8, 9, 10, and 12 have not the big change in turbidity from 1.28 to 1.83 NTU while others points located at end points of low zones and/or local low areas such as point 5, 7, 11, 13, 14, 16, and 17 are over ten times bigger than test point at pump station in turbidity. Namely, turbidity at point 14 is biggest with 14.6 NTU (17 times), next to point 5 with 12.53 NTU (15 times), point 16 with 11.45 NTU (14 times), point 13 with 9.13 NTU (11 times), point 17 with 6.55 NTU (8 times), point 7 with 3.42 NTU (4 times), and point 11 with 2.85 NTU (3 times).

After all stagnation water inside pipeline network going in private tank, the turbidity (green color) decrease rapidly but still double comparing with itself at source on average. Namely, the turbidity at test point 5 still surpass others with 5.06 NTU, followed by test point 13 with 3.66 NTU and test point 14 with 2.94 NTU. The remaining points have not too much bigger turbidity than water source that account for from 1.08 NTU to 2.46 NTU.

The turbidity at private tanks (red and purple color), in general, is smaller than at stagnation water inside pipeline network. However, after all the stagnation water going in private tanks, the turbidity is a little higher than before. Some points including 14 and 16 having turbidity between 3.45 and 5.31 NTU surpass others with around 1.6 NTU.

Table 5.44. Calculating indicator IC_9 – turbidity

No.	Indicator / Zone	1	2	3	4	5	6	7	8	9	**Average**	Weight
	Change of turbidity in pipeline network											
IC_{91}	The rate of turbidity at zones and turbidity at supply source – first time (times)	2.2	2.8	1.7	2.5	10.0	12.9	1.5	1.5	8.2	**4.8**	3
IC_{92}	The rate of turbidity at zones and at supply source in operation time (times)	1.1	1.9	1.6	1.2	2.4	2.9	1.5	1.6	3.5	**2.0**	3
	Change of turbidity before and after private tank											
IC_{93}	The rate of turbidity after and before private tanks as soon as water coming to private tanks (times)	0.5	0.7	0.5	0.5	0.2	0.3	1.0	0.9	0.2	**0.5**	1
IC_{94}	The rate of turbidity after and before private tanks in running time of service (times)	2.1	1.1	0.7	0.9	0.8	1.0	1.1	1.0	0.7	**1.0**	1
	Average turbidity of zone	**1.6**	**2.0**	**1.4**	**1.6**	**4.8**	**6.1**	**1.4**	**1.4**	**4.5**	**2.7**	

In brief, on average, turbidity of stagnation water in whole system is approximately 5 times bigger than turbidity of supply source. After all the stagnation water going into private tanks, the turbidity of water in distribution system is about twice comparing with turbidity at supply source. Comparing between zones, the turbidity of zone 5, 6 and 9 is much bigger than others (from 4.5 to 6.1 times). Thus, it can be estimated that the pipes in these zones have more leakages than others or surroundings of pipes in zone 9 contain contaminated sources.

Comparing with national technical regulation on domestic water quality QCVN 02:2009/BYT of Vietnamese Health Ministry (maximum turbidity accepted is 5 NTU), most points meet the demand of water quality, except stagnation water at some points such as point 5, point 13, point 14, point 16, and point 17.

5.2.3.2.4 Electrical conductivity (EC)

The Figure 5.29 shows that the value of EC is not significant different among test points in time (right after water coming to households or after five hours of supplying water) in space (before and after private tanks) with the value from 273 to 328 µS/cm.

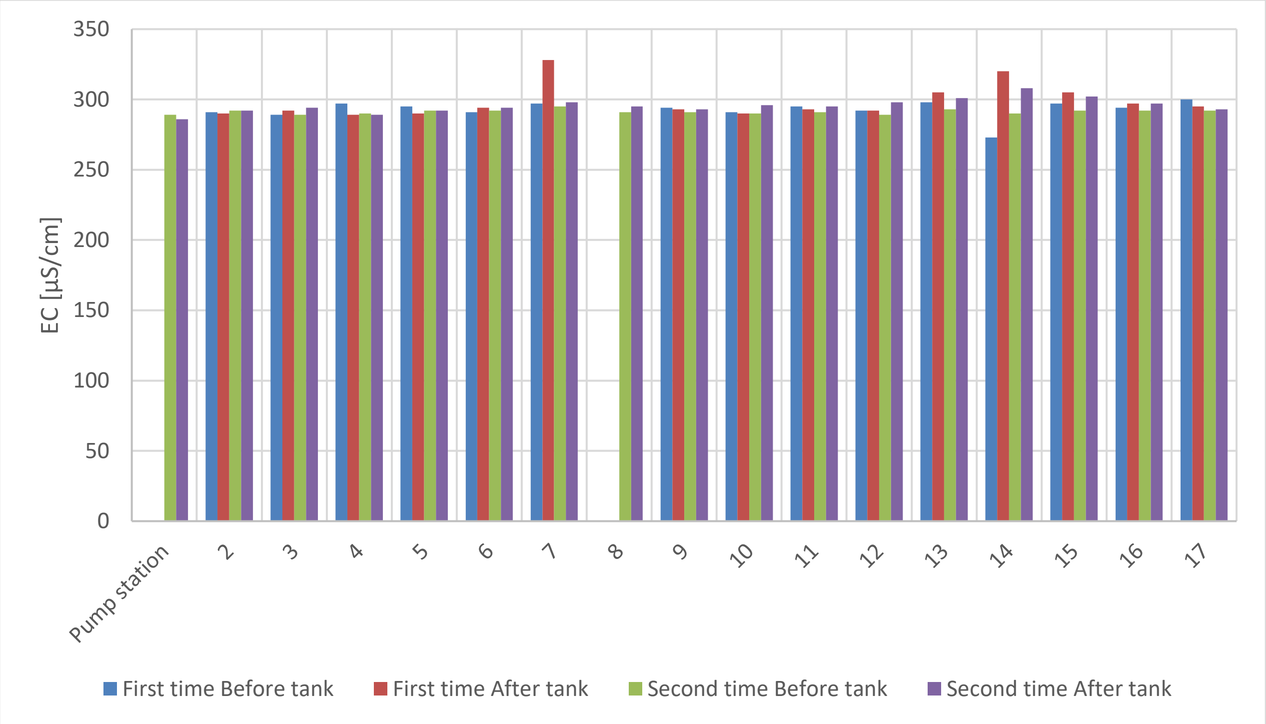


Figure 5.29. The change of electrical conductivity in WSS

The result of calculating indicators of EC including IC_{101} (EC at supply source and stagnation water of distribution system), IC_{102} (EC at supply source and water distributed in the operation time of service), IC_{103} (EC of stagnation water of distribution system and remaining water of private tank from last day), and IC_{104} (EC before and after private tank during operation time of service) show that EC is not significantly change during the process (see Table 5.45).

Table 5.45. Calculating indicator IC_{10} – EC

No.	Indicator / Zone	1	2	3	4	5	6	7	8	9	Average
	Change of EC in pipeline network										
IC_{101}	The rate of EC as soon as water coming to test points and EC at supply source (times)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	**1.0**
IC_{102}	The rate of EC at test points in running time of service and EC at supply source (times)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	**1.0**
	Change of EC before and after private tank										
IC_{103}	The rate of EC after and before private tanks as soon as water coming to private tanks (times)	1.0	1.1	1.0	1.0	1.1	1.1	1.0	1.0	1.0	**1.0**
IC_{104}	The rate of EC after and before private tanks in running time of service (times)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	**1.0**
	Average of zone	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**

In brief, it can be concluded that the intermittent water supply, distribution system, and private tanks insignificantly impact on EC of water.

5.2.3.2.5 PH

Similarly to EC, the value of PH witnesses an insignificant change among test points from 7.07 to 8.15. The change of PH at one test point is different in time (as soon as water coming to test point or after five hours of pumping water) and in space (before and after private tank), but there is no any evidences of influence of intermittent supply and private tank on the value of PH at test points.

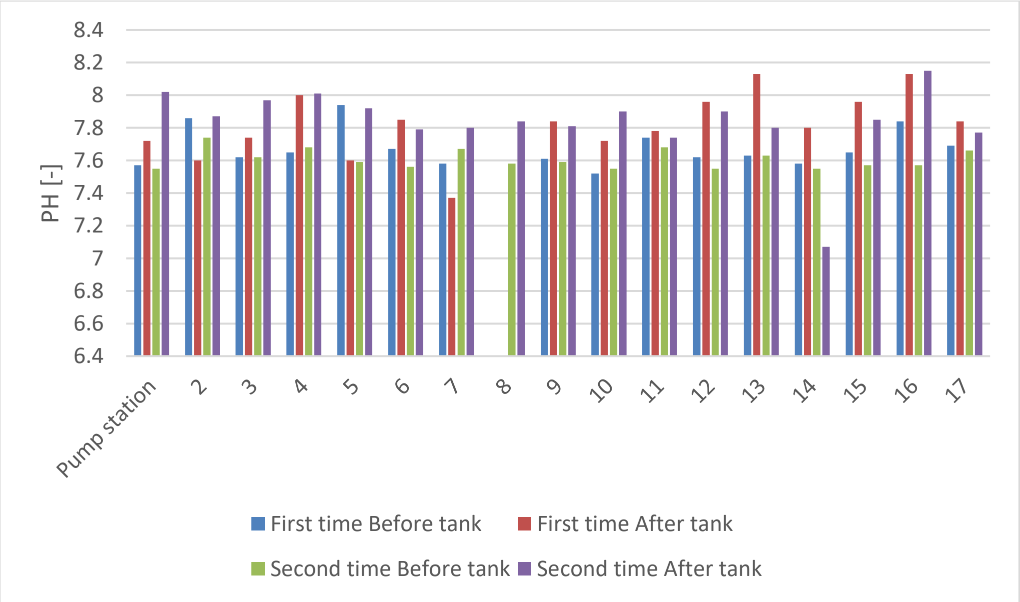


Figure 5.30. The change of PH in WSS

The result of calculating indicators of PH including IC_{111} (PH at supply source and stagnation water of distribution system), IC_{112} (PH at supply source and water distributed in the operation time of service), IC_{113} (PH of stagnation water of distribution system and remaining water of private tank from last day), and IC_{114} (PH before and after private tank during operation time of service) show that PH is not significantly change during the process (see Table 5.46).

Table 5.46. Calculating indicator IC_{11} – PH

No.	Indicator / Zone	1	2	3	4	5	6	7	8	9	Average
	Change of PH in pipeline network										
IC_{111}	The rate of PH as soon as water coming to test points and PH at supply source (times)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	**1.0**
IC_{112}	The rate of PH at test points in running time of service and PH at supply source (times)	1.0	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	**0.9**
	Change of PH before and after private tank										
IC_{113}	The rate of PH after and before private tanks as soon as water coming to private tanks (times)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	**1.0**
IC_{114}	The rate of PH after and before private tanks in running time of service (times)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	**1.0**
	Average of zone	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**

In brief, it can be concluded that the intermittent water supply, distribution system, and private tanks insignificantly impact on PH of water. Besides, comparing the value of PH at all test points with national technical regulation on domestic water quality QCVN 02:2009/BYT of Vietnamese Health Ministry (the value of PH from 6.0 to 8.5), the value of PH at all position is within allowed range of regulation.

5.2.3.2.6 Assess the impact IWS and private tank on water quality

In order to evaluate the impact of IWS and private tank on water quality, five parameters were chosen including total coliforms, E. coli, turbidity, electrical conductivity (EC), and PH. The test result and indicators of water quality show that total coliform, E. coli, and turbidity are seriously influenced at some zones while EC and PH are insignificantly impacted by intermittent supply and the presence of private tank. Comparing the calculation result with corresponding benchmark, the ranking of the subgroup belongs to class D extreme impact.

Table 5.47. The change of water quality in WSS

No.	Indicator	Total coliform	E. Coli	Turbidity	EC	PH	**Weight**
IC_9	The rate of total coliform as soon as water coming to test points and total coliform at supply source (times)	12.0	26.3	4.8	1.0	1.0	**3**
IC_{10}	The rate of total coliform at test points in running time of service and total coliform at supply source (times)	4.0	9.7	2.0	1.0	0.9	**3**
IC_{11}	The rate of total coliform after and before private tanks as soon as water coming to private tanks (times)	0.4	0.5	0.5	1.0	1.0	**1**
IC_{12}	The rate of total coliform after and before private tanks in running time of service (times)	1.1	1.5	1.0	1.0	1.0	**1**
	Change of parameters of water quality in WSS	**6.2**	**13.7**	**2.7**	**1.0**	**1.0**	

About the time: Water quality as soon as coming to households is very contaminated because most water in this time is stagnation water of pipeline network during the time of without supplying water. Namely, the number of total coliforms and E. Coli increases dozens of times on average comparing with those at supply source (total coliforms 12 times, E. Coli 26 times and turbidity 5 times on average), especially in end zone of 9 this number goes up to hundreds of times. After all stagnation water going into private tanks, the water quality of distribution system becomes better and stable, but still much bigger than itself at pump station (e.g. total coliforms 4 times, E. Coli 10 times, and turbidity two times on average).

About the space: Low and/or end points of pipeline network often have worse water quality than others. Namely, the test points have the worst water quality include point 5 of zone 9 (low and end point), point 16 and point 17 of zone 6 (low, far and end point). It is surprise that point 14 of zone 5 (little high and middle point) and point 7 of zone 2 (low and middle point) also have quite bad water quality. This can be explained that point 7 is local low, thus, stagnation water flow to this area during the time of without supplying water. However, bad water quality at point 14 is quite hard to answer. This is only estimated that there are more leakages at ahead pipes of point 14 or exists contaminated sources around this pipe area.

Figure 5.31. The picture of pipeline inside wastewater near test point 5 (zone 9)

The data from field investigation along with WSS show that most pipes of zone 9 are located inside wastewater ditch, which explains why total coliform, E. coli and turbidity of this zone much bigger than others.

The impact of private tank on water quality

The private tanks seem to be not negative impacts on water quality at all test points. Although the number of total coliforms and E. coli at private tank is higher than in pipeline network on average, but this is because of stagnation water inside pipeline network during the time of without supplying water. Besides, private tank also play an important role to reduce turbidity at all test points.

Table 5.48. National technical regulation on domestic water quality QCVN 02:2009/BYT

No.	Parameter	Unit	Maximum allowed duration
1	Total coliforms	MPN/100ml	150
2	E. coli	MPN/100ml	20
3	Turbidity	NTU	5
4	PH	-	6.0 – 8.5

Pursuant to national technical regulation on domestic water quality QCVN 02:2009/BYT of Vietnamese Health Ministry (Table 5.48), some parameters including total coliforms, E. coli, and turbidity at supply source meet the demand of Vietnamese national regulation, but when water coming to households these parameters surpass many times of the regulation. EC and PH seem to be not influenced during transportation progress and meet the demand of the regulation.

5.2.4 Conclusion

5.2.4.1 The boundary conditions: Water available resources and water demand

The water source feeding WSS exploits surface water of cliffs that its capacity goes up and down rapidly over year. Hence, total capacity of available water sources all surpasses many times comparing with water demand over year, but it is not enough for water demand at many times during the time of 7 months of dry season. Namely, indicators of availability of water source prove that the availability of water source over year (BC_{21}) is more four times bigger (445%) than SIV of supply sources, but it (BC_{22}) is not enough (81%) for water demand during dry season. Due to instability of current water source over year, SIV meets 100% water demand in a total year (BC_{11}), but only meets 81% water demand during the time of dry season (BC_{12}).

The potentiality of water sources from underground Karst cave networks is quite diversity in and around Dong Van city. Data from KaWaTech project show that there are many water caves with big amount of water in this areas such as Ma Le 1, Ma Le 2, Ma Le 3, Ma Le 4, Seo Ho, Tia Sang, and Sang Ma Sao with total flow fluctuating between 526 and 9926 l/s over year. The indicator of BC_{31} reveal that the capacity of potential water over year is around 762 times bigger than water demand whilst the capacity of potential water during the time of dry season (BC_{32}) is also 77 times bigger comparing water demand. Nevertheless, such sources is stored in deep underground Karst cave networks, which is impossible to exploit with traditional pumps. Thus, the potentiality of water source depends on the technology of exploiting water from Karst cave networks.

For these reasons, the average mark of boundary condition of system is 2.5 equivalent to classification of water scarcity in benchmark. In fact, WSS is only enough to provide for small percentage of population due to many reasons as follows: (1) the water source feeding WSS exploits surface water of cliffs that are vulnerable under the impact of weather and human factors, (2) Ineffective distribution: High rate of water losses, water distribution in WDN being not equitable in space and time. The advantaged positions can collect water anytime as long as water being supplied in system while the disadvantaged ones can receive water some hours per day with a small flow and big amount of air volume as well as worse water quality, (3) the lack of enough big storage tanks to store water in the plentiful period and supplement for water scarcity time, (4) the water waste of households at advantaged positions is also one of reasons that lead to water scarcity in WSS, (5) the pipeline system has not covered all water users in service areas.

5.2.4.2 The performance of total system

Efficiency of using physical asset: There is a big waste of using infrastructure asset in Dong Van city. The percentage of pipelines in use accounts for 82.2% and the coverage of WDN covering water users is only 74.12%. Public tanks and valves even have a much bigger waste with their rate in use being 22.81% and 33.33%, respectively. Most waste of using infrastructure asset of WDN such as pipes and public tanks is consequent by water sources drained. As the result, the benchmark of this subgroup is 1.6, which is classified in lowest level in evaluation standard (very bad). It means that physical asset of WSS in Dong Van is deteriorated extremely. Most waste of using infrastructure asset of WDN such as pipes and public tanks is consequent by water sources drained.

The coverage of water supply service: The percentage of households connected with WSS is about 61% in total households of service area, but 26% of them use other water sources such as drilled wells, rainfall, or water from cliffs at the same time. The households using both water from WSS and other sources only connect with WSS as a contingency measure in case of other source drained or not enough water. In fact, water consumption level of these households are often much lower (or even no consumption) than households using 100% water from WSS. Consequently, the benchmark of this subgroup is 1.5 in benchmark equivalent to the lowest level of evaluation standard. The low percentage of households using water from WSS originate from some causes: (1) the pipeline system has not covered all water users in Dong Van city, (2) quality of distribution service is still extreme limited such as inequitable distribution, low pressure, and intermittent supply, especially at disadvantaged positions, (3) water quality is low and not stable, especially at certain times such as after heavy rain, (4) There are some water sources in Dong Van city including water from high mountain, drilled well and rainfall. Citizens will decide water sources depending on water and service quality, expenditure, and convenience, (5) the water price of business is triple comparing with households. For this reason, many hotels and restaurants have to look for other water sources instead of water from WSS to save their operation cost.

Water supply time of service: Water supply time of system is 10 hours 5 minutes on average per year. Comparing with the benchmark, the supply time is classified in level 3 of evaluation standard. The water supply time of service is short because of some causes such as water scarcity during dry season, high difference in elevation among water users, and limitation of pump technology.

Water losses: The benchmark of this subgroup is 1.7 and is classified in lowest level of evaluation standard. The percentage of total water losses accounts for about 25% total water system input volume. However, due to high rate of air volume that occupies 7% water consumption recorded by customer meters, real loss, in fact, accounts for 31% SIV. The indicators of water losses show that air volume at the beginning of supplying water is the main reason lead to apparent losses while apparent losses due to other reasons are not worth mentioning. Besides, there is no main transmission and all public tanks are underground in Dong Van city, hence, all real losses occur at leakages on distribution system. Moreover, the infrastructure leakage index that reflect the rate between current real losses and unavoidable real loss is 6.2. It means that the potentiality of reducing real loss is very big. The system performance impacts on individual customers

5.2.4.3 The impact of system performance on individual customers

5.2.4.3.1 Inequality of distribution

In order to evaluate inequality of distribution of WSS in Dong Van city, WSS is broken into 9 different zones such as near pump station (zone 1), low and middle zone (zone 2), little high and middle zone (zone 5 and 7), high and middle zone (zone 4), low and end zone (zone 6 and 9), and highest and end zone (zone 3 and 8) based on elevation, pipe diameters as well as distance between zones and supply source.

The inequality of distribution impacts on different zones in some aspects such as distribution time, water flow, and air volume. Water users, to adapt to the inequality, have to look for solutions themselves to have enough water. There are some common solutions such as using many water sources at the same time (from WDN, water cliffs, drilled well, rainfall), building bigger private tank, or using water saver than other zones. As the result, the rate of water users connecting with WSS, level of consumption, and volume of private tanks will be different among zones in distribution network.

The indicators of inequitable distribution including eight indicators IC_1, IC_2, IC_3, IC_{41}, IC_{42}, IC_{51}, IC_{52}, and IC_6 will comprehensively evaluate the inequality of system from distribution network to customers. Namely, IC_1, IC_2, and IC_3 will evaluate the inequality of distribution network (time, water flow, and air volume) while IC_{41}, IC_{42}, IC_{51}, IC_{52}, and IC_6 will assess customer's solutions to have enough water over year (rate of customers connecting with WSS, consumption level, and volume of private tank).

The result of calculating these indicators shows that the inequality of distribution witnesses a contrast figure among different zones in WSS. The disadvantaged zones located at the highest and end points in WSS (zone 3 and zone 8) can only obtain water in 11 hours with discharge from 0.11 to 0.15 l/s and be forced to receive the big amount of air volume that accounts for about 14% consumption while, in contrast, the advantaged ones like zone 1 and 2 mostly have water collecting time equivalent to supply time of service with five times bigger discharge and a trivial amount of air volume. Other zones located at good positions such as zone 1, zone 2, zone 6, and zone 9 have the percentage of households connecting with WSS bigger than 80% and consume water from 80 to over 100 l/day/capita. Approximate half of households in zone 3 and zone 8 connect with WSS, but only 24% households in zone 3 and 21% in zone 8 use completely water from WSS. Besides, the level of water consumption at these two zones is also much lower than others with 55 l/day/capita in zone 3 and 38 l/day/capita in zone 8. Comparing with national standard of domestic water supply (from 80 to 150 l/day/capita), some zones meet the demand including zone 1, zone 2, zone 6, zone 7 and zone 9. As the result, the inequality of distribution is classified in the lowest level of evaluation standard (equivalent to very bad level).

5.2.4.3.2 The change of water quality in WDN and private tank

In order to evaluate the impact of IWS and private tank on water quality, five parameters were chosen including total coliforms, E. coli, turbidity, electrical conductivity (EC), and PH. The test result and indicators of water quality show that total coliform, E. coli, and turbidity are seriously influenced at some zones while EC and PH are insignificantly impacted by intermittent supply and the presence of private tank.

About the time: Water quality as soon as coming to households is very contaminated because most water in this time is stagnation water of pipeline network during the time of without supplying water. Namely, the number of total coliforms and E. Coli increases dozens of times on average comparing with those at supply source (total coliforms 12 times, E. Coli 26 times and turbidity 5 times on average), especially in end zone of 9 this number goes up to hundreds of times. After all stagnation water going into private tanks, the water quality of distribution system becomes better and stable, but still much bigger than itself at pump station (e.g. total coliforms 4 times, E. Coli 10 times, and turbidity two times on average).

About the space: Low and/or end points of pipeline network often have worse water quality than others. Namely, the test points have the worst water quality include point 5 of zone 9 (low and end point), point 16 and point 17 of zone 6 (low, far and end point). It is surprise that point 14 of zone 5 (little high and middle point) and point 7 of zone 2 (low and middle point) also have quite bad water quality. This can be explained that point 7 is local low, thus, stagnation water flow to this area during the time of without supplying water. However, bad water quality at point 14 is quite hard to answer. This is only estimated that there are more leakages at ahead pipes of point 14 or exists contaminated sources around this pipe area.

The impact of private tank on water quality: The private tanks seem to be not negative impacts on water quality at all test points. Although the number of total coliforms and E. coli at private tank is higher than in pipeline network on average, but this is because of stagnation water inside pipeline network during the time of without supplying water. Besides, private tank also play an important role to reduce turbidity at all test points.

Pursuant to national technical regulation on domestic water quality QCVN 02:2009/BYT of Vietnamese Health Ministry, some parameters including total coliforms, E. coli, and turbidity at supply source meet the demand of Vietnamese national regulation, but when water coming to households these parameters surpass many times of the regulation. EC and PH seem to be not influenced during transportation progress and meet the demand of the regulation.

6 Conclusions and recommendations

6.1 Introduction

Each WSS is operated with specific objectives, but always having the same target is to operate the facility asset at its maximum possible efficiency with minimum cost throughout its design period. In order to achieve this objective, performance evaluation of WSS is the first step and an indispensable part of all activities related to WSS from operation, maintenance to improvement. The implementation of any performance evaluation always has to be objective-oriented. Performance indicators play a role as a toolkit during the process of performance evaluation of WSS. In general, PIs system can be broken into three groups comprising technical, personnel/staff and financial/economic indicators in general. Three such groups have a very close interaction and interdependent relationship. For instance, a good strategy of leakage management or an optimal personnel number will increase water undertakings' revenue while financial indicators will dominate all activities of water utilities.

It was the fact that defining PIs and corresponding variables are a complicated and time-consuming progress, which requires recorded data recovering all activities related to WSS. Variables for calculating personnel and financial PIs groups are frequently not difficult to collect from operation data such as pumping diary, customer contracts, financial bills, and etcetera. Inversely, collecting variables of technical performance indicators (TPIs) is really far from easy due to WSS's very particular characteristics. For instance, most pipeline system are located underground that causes extreme challenges of detecting leakages and bursts. To identify these variables, it requires many supports from modern devices (e.g. leak detector), state-of-the-art methodologies, experts, and so on depending on specific conditions.

The technical performance evaluation of small-sized WSS grapples with more extreme difficulties in developing countries in general and in Vietnam in particular due to many reasons such as missing data for evaluation progress, lack of support devices, limitation of applying state-of-the-art methods for evaluation process due to particular characteristics of small-sized WSS. For the reasons above, technical performance evaluation of WSS, especially in small-sized WSS in developing countries is one of the most difficult steps and plays an important role in all activities related to WSS from operation, maintenance to improvement.

6.2 Review of methods for evaluating the technical performance of WSS

The current TPIs systems provide the huge number of PIs covering most possible aspects of WSS from water resources, physical asset, operation, quality of service to environment. Nevertheless, these systems seem to be only suitable with WSS in developed countries because many factors related to water supply conditions in developing countries, especially in small-sized WSS have been not mentioned. Namely, in developing world, the small-sized WSS due to limitation of available conditions (e.g. water scarcity and/or infrastructure constraints) often supplies water some hours per day contingent on available sources and customers' demand, which leads to the presence of private tanks and float valves inside water users' buildings to storage water during the period without supplying water of services. The non-continuous operation causes many unwanted consequences such as decrease of water quality and harmful effects on facilities. Besides, the presence of private tanks (maybe with float valves) not only changes hydraulics' behavior in water distribution system, but also influence negatively on water quality and inaccurate operation of customer meters. Many specific researches mentioned the problems of discontinuous supply. However, there have not been any researches dealing with this problems comprehensively.

6.3 The key TPEs for small-sized IWS in Vietnam

The research already proposed a key technical performance indicator system (TPEs) for small-sized IWS in Vietnam. Namely, the TPEs divided into three groups such as boundary conditions, the performance of total system, and the impact of system performance on individual customers, which covers all technical aspects of IWS.

6.3.1 Boundary conditions

The target of indicators of this group is to evaluate system input volume as well as ability of current and potential water sources comparing with water demand in service areas. The indicators of boundary conditions include six indicators BC_{11}, BC_{12}, BC_{21}, BC_{22}, BC_{31}, and BC_{32}. BC_{11} and BC_{12} will compare system input volume with water demand while BC_{21} and BC_{22} will reflect the rate between the volume of available water resources and system input volume over year and the period of water scarcity (dry season). Finally, BC_{31} and BC_{32} release potentiality of water sources in service area comparing with water demand in year and dry season. The six indicators will provide a comprehensive view of water sources from system input volume, availability of water resource to potentiality of water resource comparing water demand in service area.

6.3.2 The performance of total system

The performance of total system reveals through aspects comprising efficiency of using physical asset, coverage of water supply service, water supply time of service, and water losses.

Efficiency of using physical asset: In S-IWS, physical asset are frequently deteriorated or degraded after short time of operation because of various reasons like lack of investment for renovation and rehabilitation, unsuitable design, operation far from design, untrained personnel, low awareness of staffs and citizens about protecting public asset. Thus, the target of indicators of this subgroup is to evaluate efficiency of using physical asset. Namely, indicators PS_1, PS_3, PS_5 and PS_6 reflect the rate between pipes, tanks and valves and other devices in use and total physical asset of system while PS_2 shows coverage of pipeline network in service area. The indicator PS_4 will evaluate maximum water storage capacity of public tanks to supply water for WDN in case of supply sources without supplying water. All these indicators will reveal the waste of current facility and support for a plan of maintenance and rehabilitation as well as improving WDN.

Coverage of water supply service: Water from WSS is frequently not enough to supply for all water users in time and space. Hence, inhabitants who live in these areas have to look for themselves other water resources (rainfall, drilled well, and etc.) to supplement or/and instead of water from WSS during water scarcity period. As a result, water users have to use many different water sources at the same time to have enough water over year. For this reason, water users could be divided into three groups in according to water sources: (1) 100% using water from WSS (where water from WSS is the unique water supply source or advantaged locations), (2) using water both from WSS and other sources (where is diverse water supply sources or/and disadvantaged locations), (3) only using water from other sources (where is diverse water supply sources or/and disadvantaged locations). Most households using many sources will only use water from WSS when other ones are empty or very bad water quality comparing water quality from WSS. Thus, if only defining % household using water from WSS will not reflect exactly the number of households consuming reality water from WSS. Taking such characteristics in proposing PIs for coverage of water supply service into consideration, this subgroup will include two indicators PS_7 and PS_8. For example, the indicator PS_7 define rate of households connected with WSS and total households while PS_8 will identify number of households using 100% water from WSS.

Water supply time of service: The indicator of water supply time of service (PS_9) will define average operation time of water supply service per day. Normally, the longer water supply time of service is, the better the quality of service is. This indicator is a basic parameter to assess negative impacts of intermittent supply on WSS and individual customers.

Water losses: Water losses can be separated into two components apparent losses and real losses. In CWS, apparent losses come from unauthorized consumption and internal inaccuracies of meters. However, in a WSS operated intermittently, apart from internal inaccuracies of meters, there are some other causes lead to inaccuracy of measuring water consumption at households including: (1) apparent losses due to airflow at the beginning of network filling process, (2) apparent losses due to internal inaccuracies of meters, (3) apparent losses due to unauthorized consumption, and (4) apparent losses due to the present of float valves when private tank nearly full. Air volume at the beginning of network filling process often accounts for much bigger proportion than other components of apparent water losses. On the other hand, real losses are the result of leakages on components of WSS such as leakages from tanks/reservoirs, transmission mains, and distribution network. Defining real losses on WSS is far from easy because almost of all pipelines and connections are underground. Thus, real losses will be calculated by total water losses minus total apparent losses

Normally, reducing apparent losses can be achieved through a suitable process of operation and management while decreasing real losses is much more difficult because this problem relates to whole physical asset of WSS. In fact, real losses always happen in every WSS and can never be completely eliminated. A certain minimum amount of real losses will exist, which is referred to as the unavoidable real losses. Thus, the ratio between current real loss and unavoidable real losses will represent the potentiality of reducing real water losses further.

Some values are important for the process of managing water losses including total water losses, apparent losses, real losses, and the potentiality of reducing real water losses. Besides, in IWS, air volume at the beginning of network filling process often accounts for much bigger proportion than other components of apparent water losses. Hence, the air volume will be evaluated independently from other components. Therefore, the indicators of water losses group include five indicators (PS_{10}, PS_{11}, PS_{12}, PS_{13} and PS_{14}). Namely, PS_{10} and PS_{13} compare total water losses and real losses with water system input volume while PS_{11} and PS_{12} evaluate air volume and other components of apparent losses. Finally, PS_{14} reflect the gap between current real losses and unavoidable real losses.

6.3.3 The system performance impacts on individual customers

6.3.3.1 Inequality of distribution

The inequitable distribution in WSS reveals in many respects including time of collecting water of customers per day (time of water coming to connections, available time of water at every connection), air volume forced to collect at the beginning of network filling process, and average water flow at each connection. Because of these, water users located at disadvantaged zones such as high or/and far zones have to look for solutions themselves to supplement the water deficiency over year. There are some common solutions such as using many water sources at the same time (water from cliffs, drilled well, and rainfall), using less water (less consumption), or building bigger private tank. Therefore, indicators of inequality will compare the difference of available time collecting water, water and air volume, the percentage of water users connecting with WSS, consumption level, and volume of private tank at different zones.

To evaluate inequality of distribution, WSS should be divided into different zones depending on elevation (e.g. highest, high, local high, little high, little low, local low, low, and lowest), position (e.g. near supply sources, middle, end zone), distance to supply sources, pipe diameters, pipe material, important level of zone, and so on. Then, the difference of indicators among different zones reveals inequality of distribution. Normally, it can be estimated that zones located disadvantaged points (e.g. high and end zone) will have smaller amount of water flow, but forced to receive larger air volume at the beginning of network fulfill process, and shorter time of collecting water comparing other zones. However, the indicators will provide specific numbers and a comprehensive picture of inequality among zones.

There are eight indicators proposed in this group including IC_1, IC_2, IC_3, IC_{41}, IC_{42}, IC_{51}, IC_{52}, and IC_6. For instance, IC_1, IC_2 and IC_3 belonging to indicators of cause group (the system impacting on individual customers) will evaluate available time of water, water flow and air volume at different zones. On the other hand, IC_{41}, IC_{42}, IC_{51}, IC_{52}, and IC_6 belonging to indicators of effect group (solutions of customers to have enough water over year) assess the difference of consumption level, private tank volume, and number of households connecting with WSS at various zones. Name and formulation of indicators in this group is presented in Table 4.6.

6.3.3.2 Water quality

In order to evaluate the impact of IWS and private tank on water quality in distribution network, test parameters, time schedule and position of samples in ideal condition should be defined in the following:

Test parameters: Pursuant to national technical regulation on domestic water quality QCVN 02:2009/BYT, the 14 parameters of domestic water need to check including color, taste, turbidity, residual chlorine, PH, ammonia, total iron, permanganate, $CaCO_3$, chlorine, fluorine, total arsenic, total coliform, e. coli. It is the best way if all these parameters are checked for evaluation process of water quality.

However, in fact, selecting test parameters will depend on some factors such as budget, time, availability of devices and chemicals for test process. Some parameters such as total coliform and e. coli, turbidity should be prioritized to choose because they represent the spread of common underground contaminated sources (e.g. dirties, mud, bacteria). Besides, some WSS are put in special areas where can contain potential underground contaminated sources or industrial areas (e.g. arsenic, pesticides) which can go in pipeline network. Then, parameters related to the contaminated sources should be involved in test progress.

Time schedule: Most pipelines is located underground and near sewage ditch in Vietnam. Thus, if WSS is operated intermittently, these pipelines will be subjected to vacuum condition after supply hours, which can cause groundwater infiltration into the pipelines with contamination of the supply or pipes deformation. Besides, the present of private tanks inside households also have both positive and negative effects on water quality. For instance, roof tanks because of being located at the top of houses often rise water temperature, which can make a better environment for proliferating bacteria. However, roof tanks help dirt and impurities in water deposit. Therefore, to evaluate comprehensive influence of IWS and private tank on water quality, water samples should be taken at least 2 times of supplying water:

First time – as soon as water coming to customers: The target of this time is to check water quality of stagnation water in pipeline network during time of without supplying water. It is very useful for estimating leakage positions and contaminated sources around pipes. Besides, from the test result water quality at supply sources, stagnation water, and private tank are also compared.

Second time – during the period of supplying water: The target of this time to check the impact of pipeline network and private tank during running time of service on water quality. The test result is also useful for estimating leakage positions and contaminated sources around pipes if the value of test parameters fluctuates rapidly at some specific points.

Test points: Selecting positions of taking water samples are very important to evaluate the influence of IWS on water quality. Thus, choosing test points should base on difference of elevation in pipeline network, change of pipe diameter and material, diagram of pipeline network, and experience of operation and management staffs. Hence, test positions should include supply sources, points of changing elevation and/or direction and/or pipe diameter, branch points, end points of WSS, pipe positions where are estimated to occur leakages. At each test point, water samples should be taken both before and after private tank to evaluate the influence of private tank on water quality.

In order to evaluate the impact of IWS and private tank on water quality, the indicators of this subgroup will compare water quality at test points in WDN and water quality before and after private tanks with water quality at the supply source. Thus, these indicators provide a picture of changing water quality from supply sources to customers' private tanks. The results can be shown in tables or/and charts to present visual images about changing water quality in pipeline network. Namely, the indicator IC_7 will reflect the rate of water quality parameters as soon as water coming to test points and water quality parameters at supply source. It means that IC_7 will compare water quality at supply source with stagnation water during the time of without supplying water. The indicator IC_8 compares water quality parameters at test points in running time of service with water quality parameters at supply source. The target of IC_7 is to evaluate the impact of WDN on water quality during the time of without supplying water while IC_8 reflects this impact in running time of service. On the other hand, the indicators IC_9 compare water quality of stagnation water in WDN with water quality of the remaining water of private tanks from previous day, and IC_{10} compares water quality before and after private tanks during the time of running service. The target of IC_9 is to assess the influence of stagnation water in WDN on decrease of water quality at private tanks IC_{10} is to evaluate the impact of private tanks on water quality during the running time of service.

6.4 The benchmarking for TPEs

The benchmarking is important to evaluate the operation performance and classify WSS. To provide a comprehensive picture for evaluation process, the benchmark system will evaluate and classify each indicator in TPEs. Then, the benchmark of subgroup, group, and system will be defined by mark or each indicator and its weight (depending its important level). Subgroup, group, and system will be evaluated and classified in four levels of quality based on different levels of mark. In order to evaluate exactly the performance of WSS, the benchmark should be evaluated in specific groups/subgroups as follows:

Boundary conditions: The capacity of water resources will evaluate in four classes including sustainable, acceptable, water scarcity and extreme water scarcity equivalent to mark levels 4, 3÷4, 2÷3, and 1÷2. WSS with mark 4 means that SIV meet the demand at the time of evaluation and the available and potential water sources is guarantee for extend plan of WSS in the future. If WSS has mark in value between 3 and 4, it means that water sources is not enough for water demand, but not too much. The problem could be solved through small improvement plan such as optimizing distribution network, reduction of water losses. However, if WSS with the mark is less 3, the level of water scarcity will be really a big problem. Thus, a big improvement plan of WSS need to take into consideration instantly.

The performance of total system: The performance of total system will be evaluated in four levels consisting good, acceptable, bad, and very bad equivalent to mark levels 4, 3÷4, 2÷3, and 1÷2. WSS is in good classification when 100% physical asset are in use, 100% water users in service area use 100% water from WSS, water is supplied 24/24, and non-revenue water is less 10% comparing with SIV. In this level, activities of repairs and improvements are not necessary. However, if WSS is in other classifications, the performance of total system will need to be improved depending on its classification.

The inequality of distribution: The difference in average mark among zones shows inequality of distribution in WSS. The more different in mark among zones it is, the more inequitable it is among zones. Thus, the benchmark will classify the level of inequality based on the maximum difference among zones in average mark in four level including good, acceptable, bad, and very bad. Namely, the equality level of distribution will be assessed in good classification if the maximum difference of zones is less 1 in average mark. If the mark is in other levels (1÷1.5, 1.5÷2, and >2), WSS will be put in equivalent classifications such as acceptable, bad, and very bad.

The impact of IWS and private tank on water quality: The change of water quality from supply source to customers' private tanks can be classified in four levels including good, acceptable, bad, and very bad corresponding to four mark levels (1÷2, 2÷5, 5÷10, >10). The leakages of pipeline network can be estimated from test points where water quality is reduced rapidly.

6.5 The methods for collecting variables

In Vietnam, installing water meter is compulsory requirement for all water users from WSS and the indicator of customer meters is recorded by staffs of Water Undertakings monthly (pursuant to decree No.117/2007/NĐ-CP of Vietnamese government, http://vanban.chinhphu.vn). Thus, data of water consumption are available in every WSS in Vietnam. However, the remaining data are often not available or insufficient in S-IWS. To provide a general method system of collecting data variables, the research will introduce particular methods to collect all missing data.

6.5.1 Field investigation to collect data of physical asset of WSS

Target of method: Collect whole data related to physical asset of WSS

Description of method: Investigators with GPS will go along with the pipeline network to mark specific points of pipes (e.g. bend, branch, change of direction, pipe diameter, material, location, and so on) and take note important information during field investigation such as leakages in pipes (if possible). Moreover, the investigators can also collect sufficient data about physical asset of WSS during field survey comprising supply source, water treatment plant, reservoir, tank, valve, hydrant, tap, and related data. The collected data would include in some formats such as electronic data (e.g. coordinates points, route), take notes, videos, pictures, diagram, charts, and so on. The data from field investigation will enter into computer. Based on electronic data from GPS device, the map of distribution system can be drawn by using some software such as ArcMap or AutoCAD.

Device requirement: GPS (Global Positioning System), computer, and camera.

Expectation data: The data from field investigation can be divided into four kinds of data including: (1) Coordinates of specific points of pipeline network (for drawing map of distribution network), (2) Coordinates of structures, devices, and important positions in WSS (e.g. supply sources, pump station, reservoir, tank, valve, hydrant, tap, leakages, and related others), (3) Properties of physical asset (e.g. property of pipe including diameter, material, length, position (ground, underground), quality, leakages, year of installing, status), (4) Pictures and video of physical asset during the field investigation.

These data are not only necessary for calculating indicators of physical asset, but they are also mostly used for whole process of evaluating the performance of WSS.

6.5.2 House-to-house investigation to collect customer information

Target of method: The target of house-to-house investigation is to collect physical asset of water users interacting with WSS including water meter (origin, type, year of installing, running status), private tank (position, size, material, year of installing, running status), float valve (origin, type, year of installing, running status) as well as data related to water demand of water user such as number of people, occupation, type of water source used, and etcetera.

Description of method: Investigators will interview all water users in service area and fulfill questionnaires.

Expectation data: The data collected from house-to-house investigation could be broken into 4 types: (1) Coordinates of water users in service area, (2) Physical asset of water users interacting with WSS (e.g. property of private tank including location, size, material, times of cleaning per year, year of building, and status), (3) Information related to water demand such as Population, household, occupation, cost of using water per year, target of using water, complaints of customers about quality of service, and so on, (4) Picture and videos related to water users during the house-to-house investigation.

6.5.3 The method of observing customer meters

In Vietnam, 100% water users have to install water meters when they connect WSS (pursuant to decree No.117/2007/NĐ-CP of Vietnamese government, http://vanban.chinhphu.vn). Thanks to this, observing and recording data of customer meters can be implemented at all points in WSS, which is very important for analysing inequality of distribution and calculating air volume.

Target: The target of method is to identify available time of water, water flow, air volume at different connections in WSS, which is necessary for calculating indicators of inequality of distribution and apparent loss due to air volume.

Description: The experiment is carried out on site in some steps as follows: (1) Selecting customers' houses for test: Chosen positions have to cover all advantaged positions (near supply sources and/or low positions), medium positions (middle WPN), disadvantaged positions (far and/or high positions from supply sources), and special positions (local high/low points, change of diameter, direction, and so on), (2) Check water meters and private tanks of houses to make sure that these tanks are empty enough to store the water before supplying water of service, (3) Record data at these positions comprising start time of providing water of service, time when meter start running, time when water coming, time of stopping for collecting water, and indicators of water meters relevant to those times, (4) Calculate parameters: Duration of airflow and volume of air, duration of water flow and volume of collected water of households at positions.

Expectation data: The data extracted from the experiment on-site can be used to calculate some important parameters comprising (1) total air volume that customers forced to receive during the time of collecting water from WSS, (2) Data for analysing inequality of distribution (available time of water, water flow, air volume at different positions in WSS).

Besides, this method can be used to identify apparent loss due to meter inaccuracy and float valve by comparing the water volume measured by meter with net water volume.

6.5.4 Methods to measure SIV, availability and potentiality of water sources

In order to measure water input volume (SIV) at supply sources, some measurement devices can be used such as UDM200. The measurement devices would be installed on pipes after supply sources to record SIV daily. If water of the system is treated by a water treatment devices/station/plant, SIV will be defined thanks to the capacity of water treatment devices/station/plant.

In a case of without any measurement devices, building a sharp-crested weir before or after supply source could be a good idea to measure water input volume. Then, water flow of water source will be calculated as water flow through triangle sharp-crested weir. Measuring SIV follow this method is carried out in some steps as follows: (1) Build a triangle sharp-crested weir at water intake point of system before or after supply water source, (2) Record upstream levels of weir in time. This data can be recorded hourly or some times in a day contingent on change of water level by operation staffs of Water Undertaking or by an automatic instrument. (3) SIV is calculated like water flow pass a triangle sharp-crested weir.

Measuring capacity of potential sources will be proposed depending on kind of sources (e.g. surface or underground water). For example, if it is surface water such as river, lake, pond, or reservoir, we could use measurement data from department of meteorology in research area to estimate capacity of potential sources. Even if surface water is small runoff, building a sharp-created weir could be a good ideal to measure water flow. Besides, if it is underground water (e.g. water in Karst caves), capacity of potential source will mostly depend on capacity of water exploitation technology (e.g. water pump technology).

6.5.5 Methods to calculate water demand

The volume of water demand (WD) will be calculated pursuant to water supply standard of service area (Vietnamese Water Supply - Distribution System and Facilities Design Standard number TC33/2006 of Ministry of Construction).

6.5.6 Using water balance to calculate components of water losses

System input volume, water consumption, and water loss have an interacting relationship. In a WSS water system input volume is always equal to the total of water consumption and water loss. Based on water balance proposed by Alegre, et al., (2017), components of water loss such as apparent losses (air volume, meter inaccuracy, float valve, water thief) and real losses will be identified.

6.5.7 Methods to measure the change of water quality in WDN

In order on define the change of water quality from the supply source to private tank of water users, water quality needs to checked at many different positions in pipeline network as well as water samples before and after private tanks. To ensure a good result, the process of collecting data should comply with some rules as follows:

Selecting test locations: Chosen positions have to cover all advantaged positions (near supply sources and/or low positions), medium positions (middle WPN), and disadvantaged positions (far and/or high positions from supply sources), and specific points such as near local high/low points, near contaminated sources, leakages (if possible), and so on.

Choosing test parameters: It will be the best way if all 14 parameters pursuant to national technical regulation on domestic water quality QCVN 02:2009/BYT are checked for evaluation process of water quality. However, in fact, selecting test parameters will depend on some factors such as budget, time, available devices and chemistry for test process. Some parameters such as total coliform and E. coli, turbidity should be prioritized to choose because they represent the spread of common underground contaminated sources (e.g. dirties, mud, bacteria). Besides, some WSS are put in special areas where can contain potential underground contaminated sources or industrial areas (e.g. arsenic, pesticides) which can go in pipeline network. Then, parameters related to the contaminated sources should be involved in test progress.

Schedule time: Water samples will be taken at 2 times during the time of supplying water: First time – as soon as water coming to customers and second time – during the time of supplying water. So as to take water samples at the first time, collectors need to wait at test points before time supplying water of service and water samples will be collected as soon as coming to test points. In the second time, it is not stressful about time of collecting water samples. Collectors can take water samples after some hours of time supplying water of services.

6.6 The application the TPIs system for Dong Van city, Vietnam

6.6.1 The boundary conditions: Water resources and water demand

The water source feeding WSS exploits surface water of cliffs that its capacity totally depends on the amount of rainfall and to geological structure. Dong Van city are influenced by the tropical climate with the average annual rainfall is 1600 - 1700 mm/year, but not distributed evenly throughout the year. The dry season lasts seven months, from October to April, with rainfall only of about 21 - 26% of the annual rainfall. The rainy season lasts five months, from end of April to end of September, and constitutes about 74% to 79% of the annual rainfall (Nguyet et al., 2012). Besides, due to the high infiltration rates of Karst, rainfall usually assembles in underground Karst cave networks forming underground water resource, which are potential resources for the water supply in those Karst areas.

For these reasons, the capacity of current water source goes up and down rapidly over year. In fact, indicators of availability of water source prove that the availability of water source over year

(BC_{21}) is more four times bigger (445%) than SIV of Lang Nghien pump station, but it (BC_{22}) is not enough (81%) for water demand during dry season. Due to instability of current water source over year, SIV meets 100% water demand in a total year (BC_{11}), but only meets 81% water demand during the time of dry season (BC_{12}).

The potentiality of water sources from underground Karst cave networks is quite diversity in and around Dong Van city. Data from KaWaTech project show that there are many water caves with big amount of water in this areas such as Ma Le 1, Ma Le 2, Ma Le 3, Ma Le 4, Seo Ho, Tia Sang, and Sang Ma Sao with total flow fluctuating between 526 and 9926 l/s over year. The capacity of these sources is thousand times bigger than water demand of Dong Van city. The indicators of potential water source (BC_{31} and BC_{32}) are calculated with the smallest potential flow (526l/s). BC_{31} reveal that the capacity of potential water over year is around 762 times bigger than water demand whilst the capacity of potential water during the time of dry season (BC_{32}) is also 77 times bigger comparing water demand. Nevertheless, such sources is stored in deep underground Karst cave networks, which is impossible to exploit with traditional pumps. Thus, the potentiality of water source depends on the technology of exploiting water from Karst cave networks.

In brief, total capacity of available water sources all surpasses many times comparing with water demand over year, but it is not enough for water demand at many times during the time of 7 months of dry season. As the result, the average mark of boundary condition of system is 2.5 equivalent to classification of water scarcity in benchmark.

6.6.2 The performance of total system

The average mark of total system performance is 1.6 equivalent to lowest classification in benchmark. It means that the performance of total system is very bad in all aspects from physical asset, coverage of water supply service, water supply time of service and water loss. The performance of total system is evaluated in according to subgroups in the following:

Efficiency of using physical asset: The benchmark of this subgroup is 1.6, which is classified in lowest level in evaluation standard (very bad). It means that physical asset of WSS in Dong Van is deteriorated extremely. Namely, the percentage of pipelines in use (PS_1) accounts for 82%, even the coverage of pipeline network covering water users (PS_2) is lower with around 78%. Public tanks and valves (PS_3 and PS_5) even have a much bigger waste with their rate in use being 23% and 33%, respectively. The waste of using public tank (only 23% in use) leads to a fact that if water sources stop supplying water for WDN, the storage capacity of public tanks (PS_4) will solely be enough water for WDN in 0.2 day equivalent to approximately 5 hours. The waste of infrastructure asset comes from some reasons such as (1) Water sources drained, (2) Some pipes located high positions in WDN are also not in use because water cannot reach these positions such as pipes at

North – zone 8 and West direction – zone 3, (3) some other infrastructures are damaged or degraded because of the lack of maintenance.

The coverage of water supply service: The benchmark of this subgroup is 1.5. It means that the coverage of water supply service is very low and is classified in lowest level of evaluation standard. Namely, the percentage of households connected with WSS (PS_7) is about 61% in total households of service area. However, only 75% households in total households connecting with WSS (PS_8) use 100% water from WSS. The households using both water from WSS and other sources only connect with WSS as a contingency measure in case of other source drained or not enough water. In fact, water consumption level of these households are often much lower (or even no consumption) than households using 100% water from WSS. The low percentage of households using water from WSS originate from some causes: (1) Quality of water supply service has not met inhabitants' requirement. Firstly, water is directly pumped from Lang Nghien and To 5 pump stations to water users without any treatment, thus, water quality is low and not stable, especially at certain times such as after heavy rain. Secondly, the pipeline system has not covered all water users in Dong Van city. Besides, quality of distribution service is still extreme limited such as inequitable distribution, low pressure, and intermittent supply, (2) Diverse water sources: There are some water sources in Dong Van city including water from high mountain, drilled well and rainfall. Citizens will decide water sources depending on water and service quality, expenditure, and convenience, (3) Water price of business is triple comparing with households. For this reason, many hotels and restaurants have to look for other water sources instead of water from WSS to save their operation cost.

Water supply time of service: Average time of Lang Nghien pump station pumping water for WDN is about 10 hours 31 minutes in one year while To 5 pump station pumps about 4 hours 01 minute on average per year. Based number of customers supplied water by each pump station (Lang Nghien 93.5%, To 5 6.5%), water supply time of system is 10 hours 5 minutes on average per year. Comparing with the benchmark, the supply time is classified in level 3 of evaluation standard. The water supply time of service is short because of some causes such as water scarcity during dry season, high difference in elevation among water users, and limitation of pump technology.

Water losses: The benchmark of this subgroup is 1.7 and is classified in lowest level of evaluation standard. The percentage of total water losses (PS_{10}) accounts for about 25% total water system input volume. However, due to high rate of air volume (PS_{11}) that occupies 7% water consumption recorded by customer meters, real loss (PS_{13}), in fact, accounts for 31% SIV. The indicators of water losses show that air volume at the beginning of supplying water is the main reason lead to apparent losses while apparent losses due to other reasons are not worth mentioning. Besides, there is no main transmission and all public tanks are underground in Dong Van city, hence, all real losses occur at leakages on distribution system. Moreover, the infrastructure leakage index (PS_{14}) that reflects the rate between current real losses and unavoidable real loss is 6.2. It means that the potentiality of reducing real loss is very big. From house to house investigation and going along with pipeline system show that almost of all leakages occur at positions:

- Connections between main pipes with water users. Each connection often comprises close valve and water meter. Leakages usually happen at connection point between main pipe and private pipe, valve before water meter, and water meter.
- Pipes DN40 of ward 5, DN32 of 19/5 road (near Agriculture bank) and DN100 of Tran Phu road: These pipes go through stadium, Dong Van Ethnic Boarding High School, and household and are under buildings' foundation. Therefore, the structure process of these buildings caused pipe breakages. Besides, due to this, the repair and maintenance of these pipes are impossible.
- Pipes DN25 (belong to ward 5) that distribute water from To 5 pump to primary and secondary schools, and households of ward 5 are inside wastewater ditch, thus, waste water can go into pipes and causes contamination.
- Pipes DN25 of road to High Frontier Station, and DN25 of road to Frontier Post are put on the road. Some breakages is consequent by vehicles.

6.6.3 The system performance impacts on individual customers

6.6.3.1 Inequality of distribution

In order to evaluate inequality of distribution of WSS in Dong Van city, WSS is broken into 9 different zones such as near pump station (zone 1), low and middle zone (zone 2), little high and middle zone (zone 5 and 7), high and middle zone (zone 4), low and end zone (zone 6 and 9), and highest and end zone (zone 3 and 8) based on elevation, pipe diameters as well as distance between zones and supply source.

The inequality of distribution impacts on different zones in some aspects such as distribution time, water flow, and air volume. Water users, to adapt to the inequality, have to look for solutions themselves to have enough water. There are some common solutions such as using many water sources at the same time (from WDN, water cliffs, drilled well, rainfall), building bigger private tank, or using water saver than other zones. As the result, the rate of water users connecting with WSS, level of consumption, and volume of private tanks will be different among zones in distribution network.

Therefore, the indicators of inequitable distribution including eight indicators IC_1, IC_2, IC_3, IC_{41}, IC_{42}, IC_{51}, IC_{52}, and IC_6 will comprehensively evaluate the inequality of system from distribution network to customers. Namely, IC_1, IC_2, and IC_3 will evaluate the inequality of distribution network (time, water flow, and air volume) while IC_{41}, IC_{42}, IC_{51}, IC_{52}, and IC_6 will assess customer's solutions to have enough water over year (rate of customers connecting with WSS, consumption level, and volume of private tank).

The result of calculating these indicators shows that the inequality of distribution witnesses a contrast figure among different zones in WSS. The disadvantaged zones located at the highest and end points in WSS (zone 3 and zone 8) can only obtain water in 11 hours with discharge from 0.11 to 0.15 l/s and be forced to receive the big amount of air volume that accounts for about 14% consumption while, in contrast, the advantaged ones like zone 1 and 2 mostly have water collecting time equivalent to supply time of service with five times bigger discharge and a trivial amount of air volume. Other zones located at good positions such as zone 1, zone 2, zone 6, and zone 9 have the percentage of households connecting with WSS bigger than 80% and consume water from 80 to over 100 l/day/capita. Approximate half of households in zone 3 and zone 8 connect with WSS, but only 24% households in zone 3 and 21% in zone 8 use completely water from WSS. Besides, the level of water consumption at these two zones is also much lower than others with 55 l/day/capita in zone 3 and 38 l/day/capita in zone 8. Comparing with national standard of domestic water supply (from 80 to 150 l/day/capita), some zones meet the demand including zone 1, zone 2, zone 6, zone 7 and zone 9. As the result, the inequality of distribution is classified in the lowest level of evaluation standard (equivalent to very bad level).

6.6.3.2 The change of water quality in WDN and private tank

In order to evaluate the impact of IWS and private tank on water quality, five parameters were chosen including total coliforms, E. coli, turbidity, electrical conductivity (EC), and PH. The test result and indicators of water quality show that total coliform, E. coli, and turbidity are seriously influenced at some zones while EC and PH are insignificantly impacted by intermittent supply and the presence of private tank.

About the time: Water quality as soon as coming to households is very contaminated because most water in this time is stagnation water of pipeline network during the time of without supplying water. Namely, the number of total coliforms and E. Coli increases dozens of times on average comparing with those at supply source (total coliforms 12 times, E. Coli 26 times and turbidity 5 times on average), especially in end zone of 9 this number goes up to hundreds of times. After all stagnation water going into private tanks, the water quality of distribution system becomes better and stable, but still much bigger than itself at pump station (e.g. total coliforms 4 times, E. Coli 10 times, and turbidity two times on average).

About the space: Low and/or end points of pipeline network often have worse water quality than others. Namely, the test points have the worst water quality include point 5 of zone 9 (low and end point), point 16 and point 17 of zone 6 (low, far and end point). It is surprise that point 14 of zone 5 (little high and middle point) and point 7 of zone 2 (low and middle point) also have quite bad water quality. This can be explained that point 7 is local low, thus, stagnation water flow to this area during the time of without supplying water. However, bad water quality at point 14 is quite hard to answer.

This is only estimated that there are more leakages at ahead pipes of point 14 or exists contaminated sources around this pipe area.

The impact of private tank on water quality: The private tanks seem to be not negative impacts on water quality at all test points. Although the number of total coliforms and E. coli at private tank is higher than in pipeline network on average, but this is because of stagnation water inside pipeline network during the time of without supplying water. Besides, private tank also play an important role to reduce turbidity at all test points.

Pursuant to national technical regulation on domestic water quality QCVN 02:2009/BYT of Vietnamese Health Ministry, some parameters including total coliforms, E. coli, and turbidity at supply source meet the demand of Vietnamese national regulation, but when water coming to households these parameters surpass many times of the regulation. EC and PH seem to be not influenced during transportation progress and meet the demand of the regulation.

6.7 The role of the key TPEs in operation and management

The TPEs should be calculated annually. The change of TPEs among years reflects operation and management performance of WSS. Besides, comparing the TPEs with benchmarking is also necessary to know the position of WSS in national standard. The performance evaluation often take much time and cost in the first year because most essential data for evaluation are not available. Afterwards, this process will be much easier in the next years due to inheriting the data in the last year and data recorded from measurement devices installed in the system. For this reason, the performance evaluation process can be divided into two periods: First and annual evaluation.

In the first evaluation, investigators have to collect basic data such as physical asset, water customers and install control and management devices to record data for evaluation process. Due to the lack of data at the first time, the first evaluation will be limited in available data.

In the next years of evaluation, responsibility of updating physical asset of WSS and physical asset inside customer's houses as well as data related to customers would be handed over operation staffs of Water Undertakings because these staffs always come to all customers' houses monthly to record water consumption from customer meters.

6.8 The role of the key TPEs in system improvement

The TPEs will play a role as a toolkit for evaluating the performance of improvement activities. The improvement process of water distribution system normally comprises some steps such as deciding the target, selecting suitable performance indicators from TPEs, calculating chosen performance indicators before and after implementing system improvement. The improvement performance is evaluated based on comparing the change of indicators before and after improvement process. Besides, the evaluation should compare these indicators with benchmarking to know the rank of water supply system in national standard. Figure 5.32 shows steps to use TPEs in improvement process.

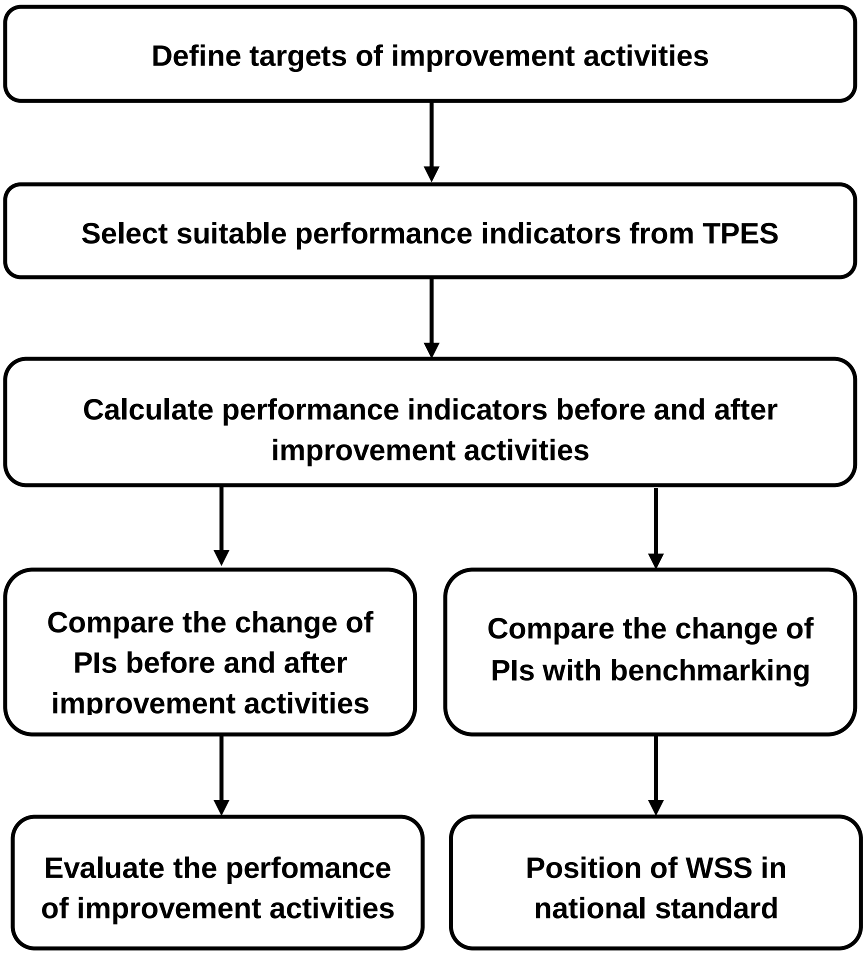


Figure 6.1. Steps to evaluate the performance of improvement activities

6.9 The role of the TPEs in KaWaTech project

The TPEs and related data play an important role during the process of conducting KaWaTech project. Namely, the data extracted from boundary condition will be necessary for deciding supply discharge for Dong Van city at the moment as well as supply plan in the future. The group of total system performance provides useful data for options of connecting water from KaWaTech project with existing pipeline system, zones where need to improve or extend pipeline system as well as operation options with the new water source. The last group will support to identify the best option of operation to minimum inequality of distribution as well as looking for solutions to minimum this negative impact. The role of TPEs in the process of implementing KaWaTech project (see Table 6.1).

Table 6.1. The role of TPEs in the process of implementing KaWaTech project

Group	Data extracted from TPEs	Using for KaWaTech Project
Boundary condition	- Capacity of current water sources and potentiality - Water demand of Dong Van city - Define the lack between water demand and current supply sources	Identify options of supply discharge for Dong Van city at the moment and future
The performance of total system	- Physical asset: Map of pipeline system, parameters of pipe (e.g. length, diameter and material), public tank (e.g. size, material), valve, hydrant, and so on. - The rate of physical asset in use in total - The coverage of water distribution pipeline system - The coverage of water supply service - Time of supplying water - Water loss and its components	- Options of connecting new water source from KaWaTech with existing pipeline system - Zones where need to extend pipeline system - Estimate zones where have higher rate of water losses - Operation options with water from KaWaTech
The impact of total system on individual customers	- Identify zones having the different influence of inequitable distribution such as the most disadvantaged, disadvantaged, medium, advantaged, the most advantaged zones - The difference between water quality at supply sources and at household taps	- Identify the best option of operation to minimum inequality of distribution - Look for solutions to minimum the impact of WDN on water quality

After finishing the implementation of KaWaTech project, the performance of this project will be evaluated by comparing the change of indicators in TPEs before and after the implementation of KaWaTech project.

6.10 Recommendations for future researches

This research developed a comprehensive toolkit to evaluate the technical performance of small-sized IWS including key TPEs, methods to collecting data variables, and corresponding benchmarking. The toolkit is suitable for quick performance evaluation of small-sized WSS where has no any supports of state-of-the-art devices. In the future, if WSS is improvement and modernization, the WSS can be converted into continuous supply system. The toolkit, then, will need to be supplemented to be suitable with new conditions.

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