

EVALUATION OF PERFORMANCE INDICATORS OF SELECTED WATER COMPANIES IN VIET NAM

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Abstract. Performance indicators of water supply company can provide important information of its service quality and business efficiency, and be intelligent basis for decision making process. The authors have analyzed key performance indicators of 19 selected municipal water supply systems in Viet Nam, including operation and design capacities, treated water quality, unit investment cost, water tariff, non-revenue water (NRW) ratio, and energy consumption rate. The average NRW of the 19 systems was 12.6 % which was lower than country-wide value of 21 %. The energy consumption rate of selected systems was ranging from 0.16 to 0.5 kWh/m³, in average 0.3 kWh/m³, which was also lower than country average of 0.35 kWh/m³, whereas the rate of energy consumption in municipal water systems in China, USA, Australia, Chile, Canada was ranging from 0.1 to 1.33 kWh/m³, depending on ground elevation, transfer distance, influent water quality, and applied technologies for water treatment and transportation. The selected water systems have applied improved treatment technologies such as mechanized coagulation-flocculation, lamella settling tank, dual media sand filter, combined contact clarifier with lamella plates, etc. The average treated water turbidity was ≤ 0.5 NTU. The domestic water tariff of the selected systems was within the country range, from 0.2 to 0.4 USD/m³. Further, the authors have indicated correlation between selected performance indicators, such as energy consumption rate and non-revenue water ratio. The analytical results showed performance indicators of top water companies in Viet Nam were in fairly good position compared to others, but improvements were still needed. Reduction of NRW ratio and keeping it at a low value are other challenges requiring water utility efforts.

Keywords: energy consumption rate, non-revenue water, performance indicator, urban water supply system, water tariff.

Classification numbers: 3.3.3, 3.4.2.

1. INTRODUCTION

In Viet Nam, in the last 35 years since the country's renovation, the level of urbanization has increased significantly. The number of urban areas has doubled from 480 in 1986 to 833 in

2019. The percentage of urban population has also doubled from 19.3 % in 1986 to 38.5 % in 2019 [1]. The urban infrastructure, including urban water supply, has also developed intensively. The operation capacity of urban water supply systems has increased from 2.2 million m³/day in 1990 to 10 million m³/day in 2019, while the proportion of urban population receiving clean water has increased from 50 % to 86 %, accordingly [1]. Along with intensive growth, the water supply systems have been facing many difficulties and challenges. Increasing loads and types of water pollution from different sources, lack of utility's capacity, limited financial sources, gaps in legal frameworks at different levels, public awareness, emerging problems due to climate change such as salt intrusion and water scarcity, etc. are among challenges for the water utilities who might need efficient management tools to deal with.

The set of performance indicators (PIs) is one of the most effective water utilities management tools, where the utility managers can recognize the progress, find the weaknesses and pending problems before taking appropriate decisions. PIs could also help to compare work performance of different water utilities located in different regions with different natural and socio-economic situations and getting lessons from each other. International Water Association (IWA) has proposed the PI system for water utilities with 6 indicators in water resources, personnel, physical facilities, operational, quality of service, economic and financial [2, 3]. The World Bank has proposed the PI system for water utilities with 7 indicators of water coverage, non-revenue water (NRW), staff productivity, operating cost, coverage ratio, collection period, affordability of water and sewerage services [4]. In the research on Portuguese water utilities, Marques *et al.* classified the PI system into 5 groups of structural indicators, operational indicators, water quality and quality of service delivered indicators, personnel and economic indicators [5]. Each group has 6-10 detailed indicators. Despite of their information values, to set up suitable set of PI, and to collect systematic database for determination of PI values for the water utilities in the country is a challenging task, requiring significant resources.

This paper presents results from the recent study in 2018 by the authors conducted for the Vietnam Association of Water Supply and Sewerage (VWSA) on the selected 19 urban water supply systems, representing different regions across the country, who has available database to VWSA for the analysis. The VWSA study was to acknowledge the top water utilities in Viet Nam based on their PIs [6]. This paper is to provide key information of performance of water utilities based on their PIs comparing to average values from available database of Vietnamese urban water sector.

2. METHODOLOGY

The water systems were classified into three groups by their design capacity as follows: (1) Large-scale system: with design capacity $\geq 100,000$ m³/day (6 from 19 systems); (2) Medium-scale system: with design capacity from 10,000 to 100,000 m³/day (6 from 19 systems); (3) Small-scale system: with design capacity $< 10,000$ m³/day (7 from 19 systems). The list of selected water systems in the study is presented in Table 1. The only abbreviated names of water systems are given, because of sensitivity of the information provided or discussed.

For assessment of performance of water treatment plants as well as the water supply system as a whole, considering possibility to gather available data at the water companies, the authors have selected key PIs including NRW ratio, treated water quality, energy consumption rate, investment cost, water tariff [2 -5]. These PIs were available throughout the gathered data of water systems, and could provide necessary, basic information for the system analysis [3, 4].

The processed values were compared with range of values (average, maximum and minimum) of respective PIs values for the whole urban water sector available from the Management Board of Urban Technical Infrastructure Projects (MABUTIP), Ministry of Construction [7].

Table 1. List of surveyed water supply systems [6].

No.	Water system	Location	Water source	Design capacity (m ³ /day)	Operation capacity, 2018 (m ³ /day)
1	TD3	Ho Chi Minh city	Dong Nai river	300,000	300,000
2	TH2	Ho Chi Minh city	Sai Gon river	300,000	200,000
3	DA	Binh Duong	Dong Nai river	180,000	200,000
4	KLH	Binh Duong	Dong Nai river	120,000	120,000
5	AD	Hai Phong	Re river	100,000	140,000
6	HDD	Ba Ria – Vung Tau	Da Den lake	100,000	120,000
7	DV	Quang Ninh	Cao Van lake	60,000	75,000
8	SB	Da Nang	Cau Do river	30,000	45,000
9	CT	Hai Duong	Thai Binh river	32,000	35,000
10	NG	Nghe An	Dao river	20,000	22,000
11	VH	Hai Duong	Thai Binh river	12,500	15,000
12	VB	Hai Phong	Thai Binh river (through irrigation canal)	12,000	12,000
13	BK	Bac Kan	Cau river	8,000	10,000
14	PT	Hue	Huong river	8,000	8,000
15	NG	Ba Ria – Vung Tau	Kim Long lake	5,000	7,500
16	CK	Phu Tho	Red river	6,000	2,200
17	SC	Phu Yen	River bank infiltration	5,000	5,000
18	PL	Soc Trang	Ground water	3,000	3,000
19	YL	Phu Tho	Ly lake	2,500	2,500

* - Average produced water amount per user, including non-revenue water from physical losses and commercial losses.

3. RESULTS AND DISCUSSIONS

3.1. Treated water quality

The treated water quality was assessed based on the turbidity, one of most commonly monitored parameter at all water companies, which was measured daily or all over the time by on-line monitoring devices. The average turbidity values of surveyed water systems were

illustrated in Fig. 1. However, some water companies did not provide enough data for processing.

All water systems had treated water quality meeting Vietnamese drinking water quality standard QCVN 01:2009/BYT, and new domestic use water standard QCVN 01-1:2018/BYT. The turbidity of treated water less than 2 NTU is the value set in Vietnamese drinking water quality standard. Water source of most of surveyed systems were surface water, river or lake. Despite of fluctuating values of turbidity in water sources over seasons, from tens to hundreds of NTU, the applied water treatment technologies (see later in the Table 3) could provide quite stable turbidity value of treated water. There were 7 water systems with average turbidity from 0.23 - 0.5 NTU, 6 systems with average turbidity ≤ 0.2 NTU, and 1 system with turbidity 0.8 NTU. Large water systems had as low average turbidity as 0.2 NTU, while medium and small water systems had a higher turbidity value, 0.5 NTU in average.

Adequate operation and management, renovation and upgrading, applying advanced technologies could be a reason for achieving low turbidity at the surveyed water treatment systems. Less than 0.2 NTU turbidity of treated water was found in the water systems with properly controlled coagulation-flocculation step, application of lamella plate clarifier (1.TD3, 9.CT, 11.VH), accelerator-clarifier (3.DA), dual media filter (5.AD, 12.VB) and pre-treatment by upflow biological contact filter U-BCF (12.VB). The water systems with turbidity of treated water of 0.23 – 0.5 NTU applied automatic chemical dosing (14.PT), accelerator-clarifier or contact clarifier with lamella plates (7.DV, 8.SB, 11.VH), HDPE block underdrain rapid sand filter (2.TH2, 14.PT), lamella plate clarifier with automatic desludging (6.HDD.15.NG). Despite of application of U-BCF and dual media filter, 12.VB system had a highest turbidity value, due to high turbidity and stabilized flocs structure in the water taken from the irrigation canal (see Table 1). The water treatment plant (17.SC) with turbidity of 0.8 NTU used Dynasand type filter which required more unique operation procedures and skilled staff [14].

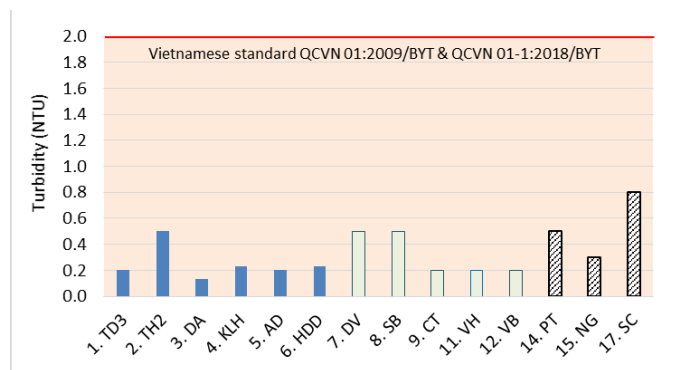


Figure 1. Treated water quality (turbidity) in surveyed water systems.

3.2. Unit cost of investment

The unit investment costs of water systems are presented in Fig. 2. Some water utilities did not provide data, probably due to sensitive reasons. The unit investment costs for the new water treatment plants were ranging from 154 to 412 USD per m³ of the design daily capacity. The figures fall in the average range of market values, including construction and equipment expenses. The average unit investment cost of large water treatment plants was 176.25 USD/m³, where average unit cost of small water plants was 259.25 USD/m³. Most of studied water

systems were using surface water source, with conventional treatment technology of coagulation-flocculation, sedimentation, rapid sand filtration, whereas tanks were made from reinforced concrete. The only 13.BK water treatment plant was made from pre-fabricated steel tanks, with self-cleaning backwashing filters, leading to the lower construction cost. However, this technology is mostly applied for remote areas, with a shorter lifetime of facilities, whereas need of more frequent backwashing and worse treated water quality are still under the discussions.

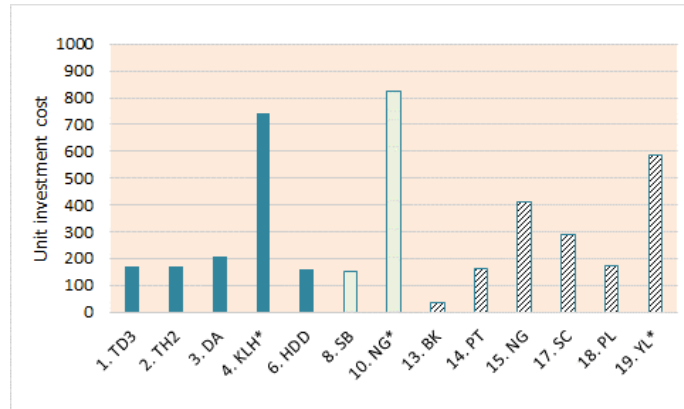


Figure 2. Investment cost of surveyed water treatment plants.

(No. 1-6: with capacity $\geq 100,000 \text{ m}^3/\text{day}$; No. 8-10: with capacity from $10,000$ to $<100,000 \text{ m}^3/\text{day}$;

No. 13-19: with capacity $< 10,000 \text{ m}^3/\text{day}$;

Unit cost was calculated for construction of water treatment plant, except for ones marked with (*): investment cost for the whole water supply system).

The unit investment costs of 4.KLH (Binh Duong), 10.NG (Nghe An), 19.YL (Phu Tho) as whole water supply systems were ranging from $586 \text{ USD}/\text{m}^3$ to $825 \text{ USD}/\text{m}^3$ of design daily capacity. The costs included expenses for construction and equipment for water treatment plants, piping network, water intake and pump stations. The investment cost for water treatment plant was about 24-44 % of total construction cost for the whole water supply system.

Time of construction was one among factors for the unit construction cost of the water treatment plant. The large water treatment plants newly built in the last 10 years such as 1.TD3 (2013-2015) and 2.TH2 (2015-2016) had unit construction cost of $170 \text{ USD}/\text{m}^3$ which was close to the average value of $176.25 \text{ USD}/\text{m}^3$. The water treatment plants were built for more than 10 years ago, such as 6.HDD had unit cost below the average value.

One important factor impacting unit construction cost was the source of funding. ODA loan projects had significantly higher unit cost compared to the plants built from local commercial loans. The average unit investment cost of the ODA plants of 3.DA, 4.KLH, 10.NG and 15.NG was 546.4 USD which was significantly more than average unit cost value. Loan conditions to purchase selective imported technologies and equipment, use of expensive foreign consultancy, expenses for different fees, and common delays made project cost higher than competitive bidding local projects [15].

3.3. Water tariff

The study focused on water tariff for domestic usage, charged to the first block of 10 m^3 per month. The values of water tariff at surveyed water systems are described in Fig. 3.

The lowest tariff was 0.17 USD/m³ in 2.TH2, Ho Chi Minh City, as per contracted wholesale tariff to SAWACO. The highest tariff was in 5.AD and 12.VB (Hai Phong city). The average domestic water tariff in Viet Nam in 2018 was 7,162 VND/m³ (eq. to 0.3USD/m³), ranging from minimum value of 4,629 USD/m³ (0.2 USD/m³) to maximum value of 12,481 VND/m³ (0.53 USD/m³). Compared with the range of water tariff in the country, the water tariff in the surveyed provinces were ranging from 0.2 to 0.4 USD/m³, which have been seen in the country range. As value of water tariff depends on expenses for labors, materials, chemicals, energy, management fees, interest rates and depreciation costs, status of non-revenue water of the system, and other factors, it was not feasible to find correlation between water tariff and impact factor from gathered data of the surveyed systems.

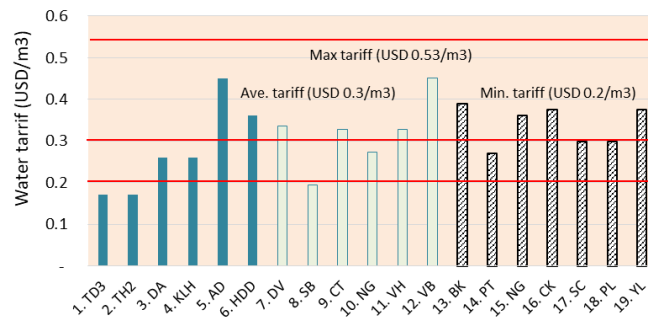


Figure 3. Water tariff at surveyed urban water systems.

3.4. Non-revenue water (NRW) ratio

The NRW is a difference between water supplied and water sold (i.e. volume of water “lost”) expressed as a percentage of net water supplied [16]. NRW ratio at a national level, based on the database of MOC [7], was average 21.0 %, max 43.8 %, min 6.2 %. Typical NRW values in large cities in Viet Nam were ranging from 22 to 28 % [8].

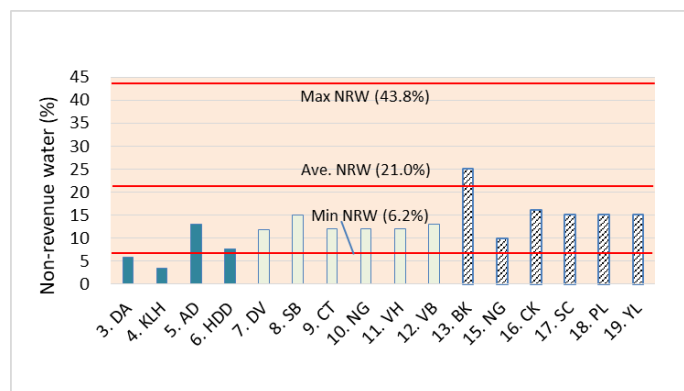


Figure 4. NRW of surveyed water supply systems compared to country-wide values, (No. 3-6: with capacity $\geq 100,000$ m³/day; No. 7-12: with capacity from 10,000 to < 100,000 m³/day; No. 13-19: with capacity < 10,000 m³/day).

With water consumption rate ranging from 80 to 304 l/cap/day, including physical and commercial losses, the average NRW ratio of surveyed 19 water systems was 12.6 %, which was

less than average ratio of the national level NRW. Less NRW values were at 1.TD3 and 2.TH2 (not shown in graph) who were providing wholesales water for the Saigon Water Company (SAWACO). NRW values of 3.DA and 4.KLH water systems in Binh Duong province were very low, 5.8 % and 3.5 % respectively. Lower than country-wide minimum NRW value was because of the wholesale of water to industrial parks in Binh Duong. It also shown high efficiency management of Binh Duong Water Company (BIWASE). Low NRW values for large water systems with capacity > 100,000 m³/day such as 5.AD in Hai Phong (13 %), 6.HDD in Ba Ria - Vung Tau (7.7 %) were typical evidence of success of good system management of the water utilities, whereas series of measurements have been applied, such as use of frequency inverters to control clear water pump station, monitoring pipe network with data logger and SCADA [6].

The only NRW ratio of 13.BK was 25 % higher than country-wide average value. 13.BK belonged to small urban water company in the mountainous area. The company was reporting its needs in capacity building, pipe network upgrading and application of NRW control measures.

At present, the NRW program is under implementation in number of urban water companies in Viet Nam. The NRW activities have significantly been enhanced after Decision No. 2147/QD-TTg dated 24 November 2010 by the Prime Minister setting up the target of NRW management to reduce NRW ratio in 2009 from 30 % to 25 % in 2015, to 18 % in 2020, and to 15 % in 2025 [9]. Besides domestic efforts, the country has borrowed the ODA loan of around USD 500 million from the Asian Development Bank (ADB) for the program. The program includes activities in public awareness raising, capacity building for local authorities and water supply companies, application of technical measures for network monitoring and maintenance. Switching to digital network management interface, some companies can now apply smart tools for asset management, flow and pressure optimization, network leakage detection, etc. By addressing NRW, the government aims to dramatically reduce investment requirements. It was estimated that reducing NRW to 15 % would increase annual revenues by USD 800 million and provide 1.3 million m³/day of additional water capacity [8].

3.5. Energy consumption rate

The energy consumption rate (ECR, kWh of total energy consumed per m³ of water produced) depends on different factors including type and characteristics of water sources, selected water treatment technology, ground elevation and system hydraulic profile design, equipment efficiency, operation optimization, etc. ECR for urban water systems in different countries are shown in Table 2.

The ECR expressed in maximum, average and minimum values at the national level were 0.78, 0.35 and 0.13 kWh per m³ of produced water, respectively (adapted from MOC database [7]). In comparison with urban water supply systems in China, New Zealand, US, Sweden, Netherlands, UK, the ECR of Vietnamese urban water systems were in the same range. In particular, the average value of Vietnamese ECR was higher than the values of Taiwan, Australia, South Africa, and lower than value of Canada. Long distance water transfer, application of advanced water treatment technologies such as ozonation for achieving drinkable water quality are main reasons of high ECR in urban water systems in developed countries [10], [17]. This shows Vietnamese water companies could fall under the big challenge to have more energy efficiency in water production in a very near future when more advancing water treatment technologies would be applied for provision of a better treated water quality to the users.

Table 2. ECR of water supply systems by countries.

No.	Country	ECR (kWh/m ³)	References
1	Viet Nam	0.13-0.78 (0.35 in average)	Calculated by authors based on MOC database [7]
2	China	0.29	[10]
3	Taiwan	0.16-0.25	[11]
4	Australia	0.01-0.2	[12]
5	New Zealand	0.15-0.44	[10]
6	US	0.184-0.47	[10]
7	Canada	0.38-1.33	[10]
8	Spain	0.11-1.5	[10]
9	Sweden	0.46	[10]
10	Netherlands	0.47	[10]
11	UK	0.59	[10]
12	South Africa	0.2	[13]

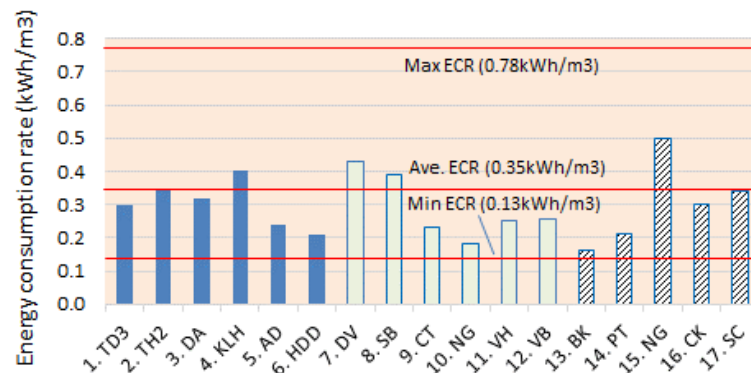


Figure 5. ECR of surveyed water systems compared to country-wide values, (No. 1-6: with capacity $\geq 100,000$ m³/day; No. 7-12: with capacity from 10,000 to $< 100,000$ m³/day; No. 13-17: with capacity $< 10,000$ m³/day).

As shown in Fig. 5, the ECR values ranged from 0.16 to 0.5 kWh/m³, in average 0.3 kWh/m³, which was lower than country-wide average. ECR of the large water systems (with capacity more than 100,000 m³/day) were from 0.21 to 0.4 kWh/m³ of treated water. The ECR of the medium size systems (with capacity from 10,000 to 100,000 m³/day) ranged from 0.18 to 0.43 kWh/m³. The ECR of the small water systems (with capacity less than 10,000m³/day) fluctuated from 0.16 to 0.5 kWh/m³ of treated water. the ECR of the surveyed water systems seems not depended on the capacity value, but depended on other factors. Long water transferring distance, with boosting pump station in 7.DV was one of the main reasons of high ECR value. Besides, application of high-energy-efficiency technology and equipment could significantly help to reduce ECR value. This is proven by the Table 3.

Table 3. Water treatment technologies, ECR, and treated water quality of surveyed systems [6].

No.	Water system	Water treatment technology	ECR (kWh/m ³)	Turbidity of treated water (NTU)
1	TD3	Mechanical mixing – coagulation – flocculation; lamella plate clarifier; improved backwashing system; SCADA	0.30	0.2*
2	TH2	Lamella plate clarifier; HDPE block underdrain rapid sand filter; ozonation; mechanical sludge dewatering; SCADA	0.35	0.5*
3	DA	Accelerator-clarifier; SCADA	0.32	0.13*
4	KLH	Contact clarifier; SCADA	0.40	0.23*
5	AD	Dual media filter; SCADA	0.24	0.2**
6	HDD	Lamella plate clarifier with automatic desludging; SCADA	0.21	0.23**
7	DV	Contact clarifier with lamella plates (after upgrading)	0.43	0.5**
8	SB	Accelerator-clarifier with lamella plates; inverter; online water quality monitoring	0.39	0.5*
9	CT	Contact clarifier with lamella plates (after upgrading)	0.23	0.2**
10	NG	Lamella plate clarifier, automatic chemical dosing; SCADA	0.18	N/A
11	VH	Contact clarifier with lamella plates (after upgrading); dual media filter; SCADA	0.25	0.2**
12	VB	U-BCF upflow biological contact filter as pre-treatment; lamella plate clarifier; dual media filter	0.26	0.2*
13	BK	Automatic chemical dosing; self-cleaning backwashing filter; frequency inverter	0.16	N/A
14	PT	Automatic chemical dosing; contact clarifier with lamella plates; filtration with dual block underdrain; alternative energy application	0.21	0.5**
15	NG	Lamella plate clarifier with automatic desludging; on-line water quality control; inverter for pump station, data logger for pipe network monitoring	0.50	0.3**
16	CK	Self-cleaning backwashing filter	0.30	N/A
17	SC	Dynasand type filter	0.34	0.8*
18	PL	Desalination by MF-RO, full automation	N/A	N/A
19	YL	Self-cleaning backwashing filter	N/A	N/A

* - Published 2019 water quality tests in water company's web-sites.

** - Data 2016 – 2018, reported by the water companies to VWSA [6].

Use of frequency inverter for the clear water pump station was among most efficient measures to reduce ECR, and the method is now widely used in urban water systems. The other measures included optimization of automatic chemical dosing and of mechanical mixing, coagulation-flocculation processes, use of contact clarifier with lamella plates, dual media sand filter, new type of filter with block-underdrain, etc. which helped to extend the filter cycle and reduce energy consumption for backwashing.

3.6. Evaluation of water system performance

Some key PIs have key relationships. Improvement of one PI could lead to change of another. For example, ECR has a relevance to NRW ratio, the relationship between them is reflected in Fig. 6. In the water system with high NRW, more water is to be taken and processed in order to compensate the lost amount. Therefore, this leads to more ECR per produced m³ of water. The nearly lowest ECR of 0.21 kWh/m³ was found in 6.HDD where the system had the lowest NRW ratio of 7.67 %. The highest ECR of 0.39 kWh/m³ was found in 8.SB where the system's NRW ratio was 15 %. This evidence confirms the need of NRW management in the water company which wants to improve energy efficiency in its water production business.

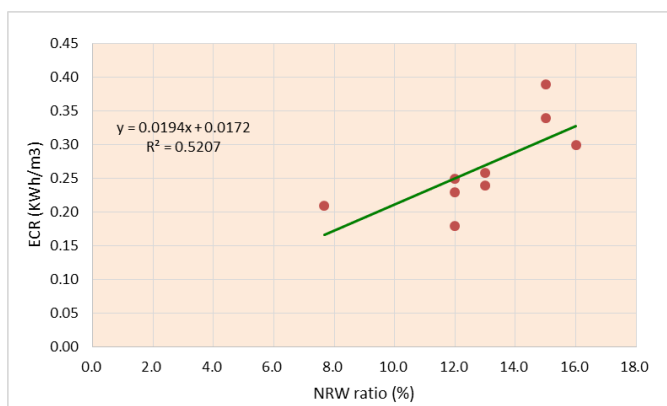


Figure 6. Relationship between ECR and NRW ratio in surveyed water systems.

4. CONCLUSIONS

Key 2018 PIs from 19 urban water systems across Viet Nam, including design and operation capacity, treated water quality, investment cost, water tariff, non-revenue water ratio, and energy consumption rate we assessed. All surveyed water systems had treated water turbidity less than drinking water standard. With efforts in upgrading of water treatment technology and operation optimization, the average treated water turbidity in selected water treatment plants was always kept ≤ 0.5 NTU, where some water systems could keep less than 0.2 NTU. The unit construction cost for the water supply systems was ranging from 154 to 412 USD per m³ of design daily capacity which depended on the selected water treatment technology, scale of the project, source of funding and associated loan conditions, and other factors. The average unit construction cost for the large water systems was 176.24 USD/m³ day capacity, and 259.25 USD/m³ day capacity for the small systems. ODA loan projects had significantly higher unit cost, 546.4 USD/m³, compared to the plants built from local competitive bidding basis. The domestic water tariffs were ranging from 0.2 to 0.4 USD/m³ which was within the country range.

The NRW ratio of the surveyed systems was in average 12.6 %, max 25.0 %, min 3.5 %, which were lower in compare with the national values, thanks to system management improvement, and investment in leakage control efforts. The ECR values of country-wide urban water systems were 0.35 kWh per m³ of produced water in average, 0.78 kWh/m³ as max, and 0.13 kWh/m³ as min. The ECR of selected water systems was ranging from 0.16 to 0.5 kWh/m³, in average 0.3 kWh/m³. ECR had a quite close correlation with the NRW ratio. High NRW leads to more energy consumption for water production, in order to compensate the lost amount. NRW management would certainly be required for the water companies aiming at energy efficiency improvement.

For the top urban water supply systems in Viet Nam, the following round values have initially suggested as referencing to evaluate the system PIs: ECR = 0.3 kWh/m³ as average achieved value; turbidity of treated water = 0.5 NTU as average achieved value; NRW ratio = 15 % as national target value for 2025. The water utilities can refer to these values to evaluate its status of performance, and to take appropriate decision for the system improvement. Good values of PIs correlate with efforts in system upgrading and optimization, which certainly lead to reduced water tariff and bring benefits not only to the water utility but also to the users.

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