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MANAGEMENT EFFICIENCY EVALUATION OF WATER SUPPLY SYSTEMS IN NORTH-EASTERN REGION OF THAILAND

Abstract:

This paper presents key findings of a comprehensive research aimed at evaluating the management efficiency of water resources and water supply systems in Thailand. The study was carried out in 4 North-Eastern provinces: Nakhon Ratchasima, Chaiyaphum, Surin, and Buri Ram. Four management aspects were examined, namely water resource, water quality, health risk, and engineering. Twenty-seven village water supply systems (VWSSs) and ten city water supply systems (CWSSs) were systematically selected and investigated. The 2 groups represent small systems in rural areas and big systems in city areas, respectively. Water samples were collected once in the rainy season and another in the dry season. For VWSSs, results indicated that 7 reservoir-using systems would have insufficient raw water ranging from 6 - 12 months per year in the next 20 years. Treated water from both surface-water and groundwater VWSSs, in some cases, had color, fecal coliform, and total coliform values which exceed drinking water standards; and had less than 0.02 mg/L residual chlorine, indicating lack of disinfection protection. Multi-route risk assessment revealed several cases of total cancer risk values higher than 10-6, though the HI values seemed to indicate no risk of concern. Evaluation of the engineering aspect predicted that 44% of the plants would have inadequate treatment capacity in the long-run. For CWSSs, it was found that most of the raw water resources – large reservoirs and major rivers – can accommodate the future water needs in the next 20 years. Most plants also have the capability to reserve excess water for usage in the dry season and have adequate reservoir sizes. A few water quality parameters were not conforming with standard, e.g. color, iron, and residual chlorine, which could be due to inappropriate operating condition. The health risk study revealed that the THMs levels were within the drinking water standards but the health risk was high in certain cases. On the other hand, the heavy metals were within standards and acceptable risk level. Most of CWSSs have a successful and efficient operation due to the appropriate structure of the organization and knowledgeable plant operators. Some plants, however, have high electricity cost which leads to loss of money in the operation. Comparison of VWSSs and CWSSs results help to understand their current management situation and discrepancy. The research outcomes are beneficial to water supply plant operators and administrators in rural and urban areas and can support relevant parties in management improvement.

Keywords:

water demand and supply, water resources, environment and development, water supply systems, general welfare

JEL Classification: Q25, Q56, L95

1 Introduction

Providing safe and adequate water supply is an important priority for local authorities in order to maintain the good health of the population. Other than the capital city, Bangkok, each of the 76 provinces of Thailand has 2 main groups of water supply systems: village water supply systems (VWSSs) and city water supply systems (CWSSs). VWSSs are small water supply systems in the rural area which were mostly constructed by governmental agencies and handed over to the communities for operation by either village committees or subdistrict administration organizations (SAOs). On the other hand, CWSSs are mostly medium to large systems serving the population in urban areas. They are constructed, owned and operated by city or town municipalities, or the Provincial Waterworks Authority of Thailand (PWA). Therefore, dissimilarity exists between the 2 groups in many aspects of operation and management.

Many VWSSs throughout the country face technical and management problems. Table 1 shows the data of water supply systems in the villages of Thailand and the 4 provinces selected in this study (DWR, 2009). The proportion of villages which need improvement in the study area (26%) are very close to those of the country (28%); while the proportion of villages not having water supply systems in the study area (15%) is substantially higher than those of the country (9%). For CWSSs, some of the aforementioned problems also exist but are not as crucial. Generally well-equipped with manpower, technical knowledge, and steady budget, their concerns are more of the cost-effectiveness of plant operation. They also need to be in control of the system management in order to efficiently deliver satisfactory service to the dense population area.

Table 1: Status of water supply systems in the villages of Thailand and the study area

Province /Area /Country	No. of Village	Have Water Supply System					Not Have Water Supply System	
		Total	Acceptable		Need Improvement			
		(Village)	(Village)	(%)	(Village)	(%)	(Village)	(%)
Nakhon Ratchasima	3,693	3,218	1,941	60	1,277	40	495	13
Chaiyaphum	1,574	1,535	1,163	76	372	24	41	3
Buri Ram	2,527	2,146	2,095	98	51	2	381	15
Surin	2,103	1,528	1,069	70	459	30	579	28
Study Area (4 provinces)	9,897	8,427	6,268	74	2,159	26	1496	15
Thailand	74,073	69,087	49,818	72	19,269	28	6,491	9

Source: Department of Water Resources (2009)

In order to study the existing status and evaluate the management efficiency of the 2 groups of water supply systems in Thailand, this comprehensive research project was developed which comprises of 4 sub-projects. The specific objectives of individual sub-projects were 1) to evaluate the water resource potential of the water treatment systems for supporting existing and future demands, 2) to evaluate the quality of water in the systems, 3) to assess the health risk from consumption of the water, and 4) to evaluate the engineering- and management-related aspects of the water supply treatment plants. This paper presents the essence of findings integrated from all 4 sub-projects.

2 Methodology

This study selected the north-eastern region of Thailand as the study area, specifically the lower 4 provinces: Nakhon Ratchasima (NR), Chaiyaphum (CP), Buri Ram (BR) and Surin (SR). The 2 groups of water supply systems were selected proportional to the number and types of systems which exist in each province. For VWSSs, 27 locations were selected, which could be further characterized into 2 sub-groups based on their water resources: surface-water (17 locations) and groundwater (10 locations). For CWSSs, 10 locations were selected, with additional criteria that each province must have systems operated by municipalities as well as systems operated by PWA.

At each location, the plant operator was interviewed and administered by research questionnaires. The plant's water resource, treatment units, and auxiliary systems were surveyed and examined. Three water samples – raw water, treated water, and household tap water – were collected at each location and analyzed for general parameters: color, turbidity, temperature, pH, conductivity, TS, TSS, TDS, DO, BOD5, chlorine residual, nitrate, nitrite, iron, manganese, calcium and magnesium hardness, fluoride ammonia, TKN, total coliform, and fecal coliform. All analyses followed the procedure described in Standard Methods of Water and Wastewater Examination (APHA, AWWA, and WEF, 2005). In addition, the household tap water samples were sent to Metropolitan Waterworks Authority of Thailand laboratory for analysis of 4 species of THMs – Chloroform ($CHCl_3$), dichlorobromomethane ($CHCl_2Br$), chlorodibromo methane ($CHBr_2Cl$), and bromoform ($CHBr_3$) – using gas chromatography with ECD detector of head-space technique. Inhalation, ingestion, and dermal absorption exposure from tap water were subsequently assessed in order to characterize THMs lifetime cancer risks and hazard indices. The deterministic exposure approach was used in the assessment, based on the U.S.EPA guidelines (U.S.EPA, 2005; U.S.EPA, 2002). The data collection, site survey, and water sampling were carried out in two periods: rainy season (July-October) and dry season (April-May). Phase I and II of the research, the VWSS and CWSS study, was completed in 2014 and 2018, respectively.

3 Results and Discussion

3.1 Capacity Evaluation

Table 2 summarizes the data of 37 water supply systems selected in the 4 provinces of this study (Kosa et al., 2017). Currently, Thailand's population is approximately 69 million people and its area is 513,120 km^2. The study area of 4 provinces have occupants of 6,728,450 people and amounted to 51,719 km2, which is 9.8% and 10.1% of Thailand, respectively. The agencies responsible, from small to large size organization, are village committee, subdistrict administration organization, subdistrict municipality, town municipality, city municipality, and provincial waterworks authority.

Of the 17 surface-water VWSSs studied, 5 of them receive raw water from dams or rivers and had minimal concern for water sufficiency. The other 12 locations have their own reservoirs. In 2011, half of the reservoir-using VWSSs had sufficient water input. These were medium to large system with sizable reservoir, 76,800 - 640,000 m^3, which are typically filled up around July and gradually lowered when the dry season approaches. The other half had 4 - 12 months with insufficient water input per year. They were small to medium system with undersized reservoir, 94 - 32,000 m^3. Furthermore, in the next 20 years, 7 reservoir-using VWSSs would have insufficient water ranging from 6 - 12 months per year. Reasons for insufficient raw water resources were identified as follow. First, the reservoirs were undersized compared to the treatment plant capacity. Second, the water supply demand was not in correlation with the amount of water collected in the reservoirs. Third, many reservoirs were located on flat terrain with no catchment area other than the reservoir surface areas. The final reason, there was neither backup plans for drought incidents nor expansion or management plans to accommodate the future demand of the communities. Understanding these causes could be helpful for all parties trying to improve the situation.

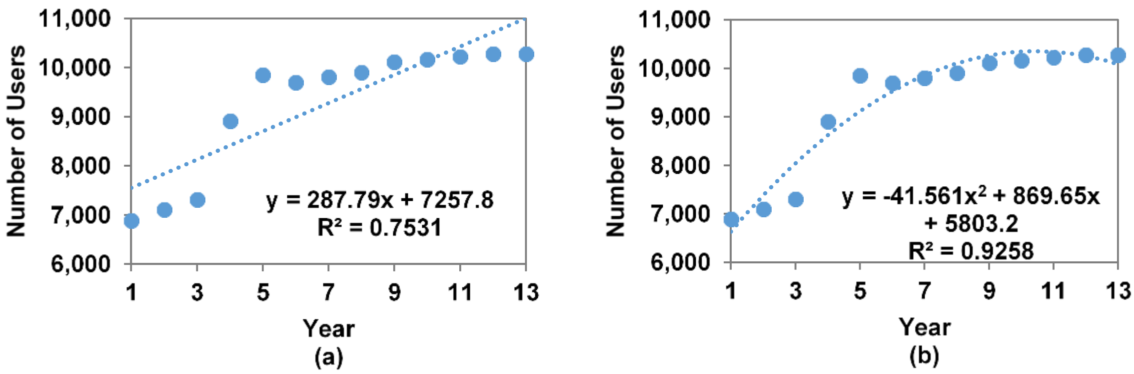
Table 2: Water supply system data in the 4 provinces of this study

Province	Water Supply System	Code	Raw Water Resource	Resource Capacity	Responsible Agency*
Nakhon Ratchasima (Population 2,639,226 Area 20,494 km^2)	CWSS	UK1	Lam Takong river	14,000 m^3/d	CM
		UK2	Reservoir	1,227,744 m^3	TM
		UK3	Lam Sae river	3,360 m^3/d	PWA
		UK4	Mun river	5,760 m^3/d	PWA
	VWSS	RK5	Lam Chakkarat river	662 m^3/d	SAO
		RK6	Reservoir	80,000 m^3	SAO
		RK7	Reservoir	608,560 m^3	SM
		RK8	Reservoir	8,000 m^3	SAO
		RK9	Reservoir	160,000 m^3	SM
		RK10	Groundwater	75 m^3/d	SM
		RK11	Groundwater	21 m^3/d	VC
		RK12	Groundwater	27 m^3/d	VC
		RK13	Groundwater	50 m^3/d	VC
Chaiyaphum (Population 1,139,356 Area 12,778 km^2)	CWSS	UC14	Klum river	5,280 m^3/d	SM
		UC15	Che river	13,200 m^3/d	PWA
	VWSS	RC16	Huay Sam Mao River	No data	SAO
		RC17	Reservoir	32,000 m^3	SAO
		RC18	Groundwater	100 m^3/d	VC
		RC19	Groundwater	12 m^3/d	VC
Buri Ram (Population 1,591,905 Area 10,323 km^2)	CWSS	UB20	Reservoir	1,040,000 m^3	SM
		UB21	Reservoir	1,470,000 m^3	PWA
	VWSS	RB22	Reservoir	640,000 m^3	SM
		RB23	Reservoir	22,400 m^3	SAO
		RB24	Reservoir	76,800 m^3	SAO
		RB25	Reservoir	19,200 m^3	SAO
		RB26	Reservoir	24,000 m^3	SM
		RB27	Groundwater	45 m^3/d	VC
		RB28	Groundwater	46 m^3/d	VC
Surin (Population 1,397,180 Area 8,124 km^2)	CWSS	US29	Reservoir	1,073,000 m^3	TM
		US30	Reservoir	4,000,000 m^3	PWA
	VWSS	RS31	Reservoir	640,000 m^3	SAO
		RS32	Reservoir	89,600 m^3	SAO
		RS33	Reservoir	14,400 m^3	SAO
		RS34	Reservoir	10,000 m^3	SM
		RS35	Groundwater	125 m^3/d	VC
		RS36	Groundwater	30 m^3/d	SM

*VC = Village Committee, SAO = Subdistrict Administration Organization, SM = Subdistrict Municipality, TM = Town Municipality, CM = City Municipality, PWA = Provincial Waterworks Authority

In contrast, all 10 CWSSs in this study have sufficient raw water in all 12 months of the year. They either receive raw water from large reservoirs or major rivers and store it in their own reservoirs. Although the original purpose of large reservoirs is to serve agricultural demand, they also have a role in supporting CWSSs' need for raw water, especially when drought occurs. In addition, most plants have the capability to reserve excess water for usage in the dry season and have adequate reservoir sizes. Two mathematical models derived from data in the past were used to predict the number of future users for each system (Figure 1). The results of water users and water demand prediction showed that the present and future needs of the CWSSs can be met and hence were not of concern.

Figure 1: An example of models for predicting user numbers of UB20: (a) linear regression equation and (b) polynomial equation



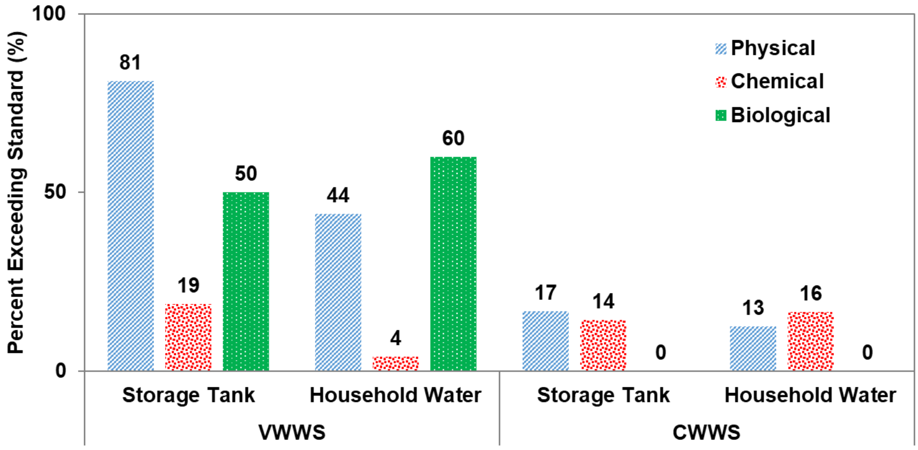
3.2 Water Quality Assessment

For surface-water VWSSs, the raw water had several parameters with values exceeding standards, notably ammonia, total coliform, and fecal coliform. Meanwhile, some groundwater VWSSs had pH, conductivity, TDS, hardness, total coliform, and fecal coliform higher than standards. For treated water, over 30% of the surface-water VWSS water samples had color and coliform values exceeding standards. The latter was also true for the groundwater VWSSs. In addition, both systems had residual chlorine less than the criteria value of 0.02 mg/L. For household tap water, results were largely in agreement with the treated water. High coliform counts most likely occurred due to the fact that several groundwater-using VWSSs did not have disinfection units.

For CWSSs, results show that some systems had raw water parameters exceeding standards such as color, BOD, manganese, nitrate, and total coliform (Yimrattanabovorn et al., 2018). The reason could be that contamination of wastewater from urban area occurs at the upstream of rivers which serve raw water to those CWSSs. For treated water and household tap water of some CWSSs, color, iron, and manganese were exceeding standards. Residual chlorine levels of the samples were found to be less than desired. Nevertheless, the biological quality of the water in both locations was in good status, i.e. no samples exceed the biological standard.

Comparison of water quality between VWSSs and CWSSs at storage tanks (clear well) and at household locations are shown in Figure 2. It is apparent that VWSSs have higher percentages of sample exceeding standards. Specifically, for household water samples, VWSSs have 60% of samples exceeding the biological standard, while CWSSs have none. These outcomes provided a sense of urgency for responsible parties to improve their water quality treatment practice.

Figure 2: Comparison of water quality between VWSSs and CWSSs at storage tanks and at households



3.3 Health Risk Assessment

Only the 17 surface-water VWSSs were selected for THM analyses since groundwater VWSSs typically did not have chlorination units and thus were less likely to have THM concerns. The results of household tap water samples showed that $CHCl_3$ was the most abundant among the 4 THM species analyzed. On the other hand, $CHBr_3$ was not detected in any of the samples. Total THM values ranged from 1.87 – 48.46 μg/L, which were lower than standards. Cancer risk from dermal absorption and inhalation exposure to the 4 THMs was estimated to be lower than the U.S.EPA acceptable level of 10^{-6}. However, the ingestion route was the major contributor to the exposure to these chemicals. When three exposure routes were combined, it was found that total cancer risk values were higher than 10^{-6} in all locations for the female population, and in 6 locations for the male population. The species which contributed the most were $CHCl_3$ and $CHCl_2Br$ – both are group B2 of probable human carcinogen. Based on these estimations, related health agencies should pay more attention to the cases and carry out a more in-depth risk assessment. On the contrary, HI values of single-route and multi-route exposure assessment showed negligible risk, i.e. less than unity, from exposure to individual or all species of THMs.

For CWSSs, results showed THMs in water supply and tap water points were within the World Health Organization recommendations (Pentamwa et al., 2017). Similar to VWSSs, $CHCl_3$ was the most abundant among the 4 THM species and $CHBr_3$ was not detected in any of the samples. Total THM values ranged from 2.37 – 60.09 μg/L, which were a little higher than VWSS but still lower than standards. Cancer risk assessment through 3 routes of exposure found that the only significant route was ingestion. The highest risk value for THM was 5.11×10^{-6}, which is slightly above the acceptable risk of 1×10^{-6}. It was also found that females have higher risks than males. The risk of cancer from individual specie from lowest to highest were $CHCl_2Br$, $CHCl_3$, $CHClBr_2$, and $CHBr_3$, respectively. For non-carcinogenic health risk, it was found that all HI value was below 0.17, which is considered an acceptable risk.

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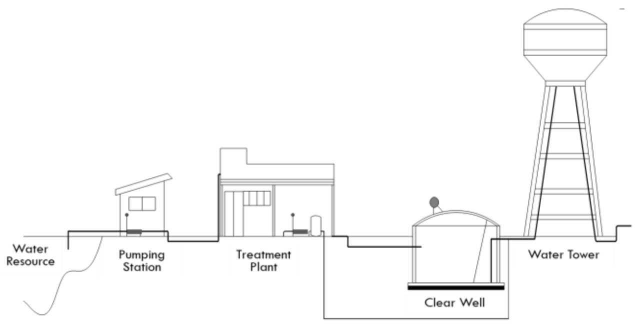
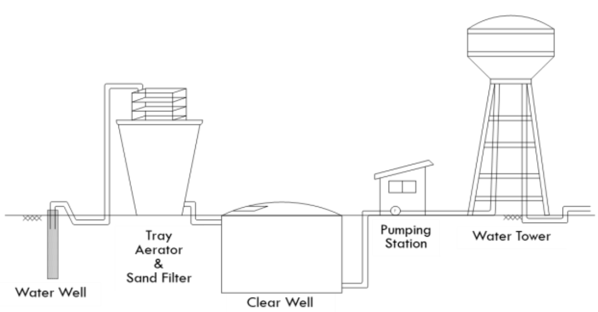
3.4 Engineering and Management Evaluation

Figure 3 illustrates the typical unit operation of surface and groundwater VWSSs. A surface-water plant normally consists of a pumping station, a coagulation unit, a flocculation unit, a sedimentation unit, a sand filter, a clear well, and a water tower. A groundwater VWSS normally consists of a pumping station, a tray aerator, a sand filter, a clear well, and a water tower. It is possible, however, to find small groundwater systems without any water treatment process. Furthermore, the chlorination process does not always exist in small VWSSs. For CWSSs, the treatment process was conventional and more standardized. All 10 systems were of rapid sand filtration type and use surface water as input. The water treatment process consists of raw water pumping, rapid mixing of chemicals, coagulation, flocculation, sedimentation, rapid sand filtration, disinfection, storage, and distribution (Racho et al., 2017).

Figure 3: Typical unit operation of VWSSs: (a) surface-water VWSS and (b) groundwater VWSS



(a)



(b)

Table 3 summarizes the operational and management data of all systems. The design capacity of 27 VWSSs studied ranged from 5 – 20 m^3/hr and the actual water production was in the range of 437 – 12,960 m^3/month. In contrast, the 10 CWSSs' design capacity ranged from 140 – 3,000 m^3/hr, with actual water production from 31,104 – 4,145,000 m^3/month. In general, a significant amount of water produced is lost in the distribution system. This loss can be estimated based on production and revenue information. The average value of loss for VWSSs and CWSSs were quite close, 20.7% and 21.8%, respectively. The median value of VWSS suggested that its mean was positively biased by exceptionally high values of certain systems. Although these loss values were not unusual, they indicated defective piping systems. To minimize the problem, engineers should carry out a water balance analysis and try to locate and fix faulty connections, leaking pipes. Water meters may be needed in certain locations of the distribution system for monitoring purposes.

On the plant operation aspect, most VWSSs did not operate properly as designed and most plant operators had little or no relevant technical knowledge or training. All groundwater systems and 5 of the surface-water systems did not have or practice disinfection. Evidently, more governmental attention and budget is needed for improvement of the physical plant as well as the quality of personnel. For CWSSs, there were no significant issues in this regards since the plant operators were scientists or engineers who were knowledgeable and properly-trained.

On the management aspect, it can be seen from Table 3 that the unit electricity costs varied widely (0.5 – 48.2 Baht/m^3) but not so much for the unit chemical costs (0.0 – 10.7 Baht/m^3). The revenue was slightly higher for CWSSs. For VWSSs, 6 out of 27 plants (22%) suffered from insufficient revenue collection that did not cover water treatment costs. The corresponding values for CWSSs were 3 out of 10 (30%). These systems continually require extra support from the government and therefore were not self-sustained. To reduce the dominant cost – electricity bill – the plant management could adopt these practices: use optimum-sized pumps, have good maintenance of pumps, use multiple small pumps instead of one big pump, use the pump during the off-peak period, and use sufficiently large clear well to avoid on-peak pumping. Moreover, reducing water loss could also be valuable, as well as improving database system and revenue collection efficiency.

Table 3: Operational and management data of VWSSs and CWSSs

Group	Statistics	Water Produced (m^3/mth)	Water Loss (%)	Cost per m^3 (Baht) (100 Baht is approximately 2.78 Euro)			Revenue per m^3 (Baht)
				Electricity	Chemical	Total	
VWSS (n=27)	Average	2,562	20.7	3.7	1.0	4.6	8.8
	Median	1,927	11.5	2.2	0.2	3.2	6.0
	Minimum	437	0.0	0.5	0.0	0.5	0.9
	Maximum	12,960	85.0	12.5	4.4	14.9	52.0
CWSS (n=10)	Average	749,935	21.8	9.7	3.5	13.2	11.3
	Median	150,000	21.5	1.8	2.2	3.5	10.6
	Minimum	31,104	1.9	0.7	0.1	1.8	3.8
	Maximum	4,145,000	54.7	48.2	10.7	58.9	22.8

4 Conclusion

Results presented in this paper were integrated from a 4-component comprehensive research regarding water sources, water quality, health risk, and engineering and management of rural and city water supply systems in the north-eastern region of Thailand. Among essential findings were water resource capacity prediction, water quality assessment for raw water, treated water, and household tap water, estimation of risk from exposure to 4 species of THMs in water, evaluation of treatment plant units, operation, and management. Comparison of the two groups – VWSSs and CWSSs – help to understand their similarity and discrepancy. The overall findings provided guidance for relevant parties toward improvement in the future, including the communities, local administration organizations, and governmental agencies.

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