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ASSESSING URBAN WATER SUPPLY SYSTEM IN NORTHEASTERN THAILAND: WATER QUALITY AND AUTHORITY ORGANIZATION

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ABSTRACT: Providing safe water supply is one of the important public health priorities, the water quality of water supply is closely associated with human health. The aim of this study was to assess the quality of water in the urban water supply systems and their authority organizations including the existing performance of the water supply systems and their organizations. The sampling locations were covered by 4 cities, namely Nakhon Ratchasima (Korat), Chaiyaphum, Buriram and Surin provinces. There was the total of 13 sampling site locations of the urban water supply systems which are owned by the provincial and municipal waterworks authorities. Water samples of each sampling site location were collected from water resources, storage tanks, and household water taps, and analyzed for various parameters. The results showed that the water quality of the urban water supply systems had met the water quality standards for the parameters: turbidity, TSS, TDS, Nitrate, and total coliform, except color and iron due to the retention time of the sedimentation process which was not the proper range. Besides, there were problems with the residual chlorine in storage tanks and household tap water which was lower than the standard limit and might affect population health. There was no difference between the performance of the provincial and municipal waterworks authorities. The outcome of this study can support the improvement of the urban water supply systems and their authority organizations.

Keywords: Water supply, Water quality, Provincial waterworks authority, Municipal waterworks authority

1. INTRODUCTION

Access to the safe water supply is a basic concern for human health and health protection. According to the World Health Organization (WHO), a concentration of microorganisms, parasites or substances posing a possible risk to human health has to be prevented [1]. The water quality of water supply is closely associated with human health. If the water supply was contaminated by pollutants and microorganisms, it would affect water qualities and the health of the population. Thus, water supply systems and authority organizations are obliged to monitor water quality for human consumption. The water qualities need to meet the standard, which is why the quality of water resources and tap water of water supply systems should be assessed to state aspects of problems. Water supply in urban areas is challenged by increasing population. In this study, the sampling locations were covered by 4 cities, namely Nakhon Ratchasima (Korat), Chaiyaphum, Buriram and Surin provinces. This region covers more than one-third of the country which is called “Korat plateau”. The water supply consumption in this area has been seriously concerned because of the low level of rainfall intensity and a long dry period in this area. This study is one of four sub-projects in the research project, “Study of Management Efficiency of Water Resources and Urban Water Supply Systems in North-Eastern Region in Thailand”. The main goal was to thoroughly evaluate the existing urban water supply systems in the northeastern region of Thailand in terms of water resources, water quality, associated health risks and engineering aspects. The aim of this study was to assess the quality of water in the urban water supply systems and their authority organizations including the existing performance of the water supply systems and their organizations. The outcome of this study can support the improvement of the urban water supply systems and their authority organizations.

2. METHODS

2.1 Study Sites and Sampling

This study was carried out to collect water from the urban water supply system in the lower northeastern of Thailand. The area covered 4 provinces, namely Nakhon Ratchasima (N), Chaiyaphum (C), Buriram (B) and Surin (S) provinces as shown in Fig.1. The urban water supply system typically consisted of the coagulation-flocculation, sedimentation, filtration, and disinfection systems. The water source of the water treatment system was commonly taken from the surface water. The water supply systems in northeastern Thailand are organized by two organizations: the provincial waterworks authority

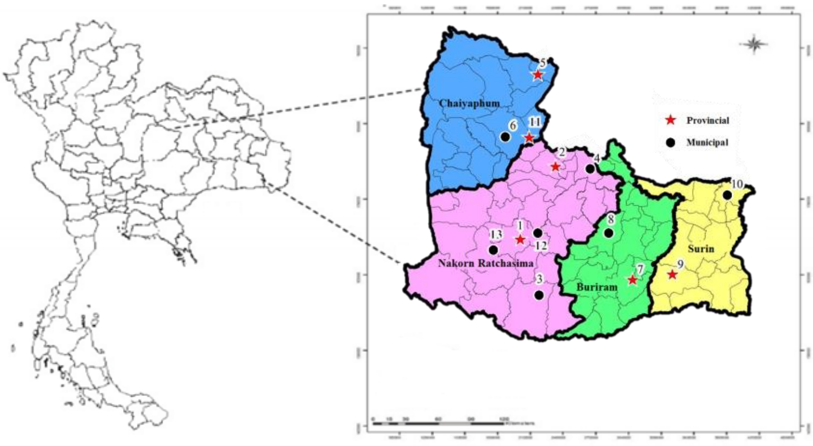

Fig.1 Map of the study area and the sampling locations

and the local authority. Thus, this study focused on the urban water supply systems owned by the provincial and municipal waterworks authorities. The total of 13 sampling site locations of the urban water supply system was collected during the dry period (January-April, 2016) and the rainy period (July-October, 2016). The distribution of the 13 sampling site locations was shown in Table 1.

2.2 Analytical Methods

Water samples of each sampling site location were collected from water resources, storage tanks and household water taps. Water samples were analyzed for various parameters by analytical methods as shown in Table 2.

Table 1 Sampling site locations of the urban water supply system

Study area	Authority organization		
	Provincial	Municipal	Total
N	2	4	6
C	2	1	3
B	1	1	2
S	1	1	2
Total	6	7	13

2.3 Data Analysis

2.3.1 Water quality assessment

The results of the water quality were checked with the guideline of World Health Organization (WHO) for the water resources quality and the standard of the metropolitan waterworks authority and for the storage tank water quality and the household tap water quality as shown in Table 3. The percentages of the water samples that did not exceed the standard were calculated by using the Eq. (1)

$$\%\ Not\ exceed\ standard = \frac{Number\ of\ samples\ that\ were\ not\ exceed\ standard}{Total\ sample} \times 100 \quad (1)$$

2.3.2 Static analysis

The results of the water quality of the provincial and municipal waterworks authorities were analyzed by mean and standard deviation (SD) and analysis of variance with an Independent Sample Test (2-tailed) SPSS Statistics Version 22.0.

Table 2 Parameters and analytical methods

Parameters	Analytical methods [2]	Parameters	Analytical methods [2]
Physical and Chemical quality		*Physical and Chemical quality*	
Turbidity	2130 B. Nephelometric Method	Nitrite, Nitrate	4500-NO_2^-, NO_3^- B. Spectrophotom
Colour	2120 D. Spectrophotometric Method	Fluoride	4500-F^- D. SPADNS Method
BOD	5210 B. 5-day BOD Test Method	Ammonia-N	4500-NH_3 C. Titrimetric Method
Iron	3500-Fe B. Phenanthroline Method	TKN	4500-Norg Kjeldahl Method
Manganese	3500-Mn B. Persulfate Method	TDS, TSS	2540 C., D. Gravimetric Method
Hardness	2340 C. EDTA Titrimetric Method	Residual chlorine	4500-Cl B. Iodometric Method
Sulfate	4500-SO_4^{2-} E. Turbidimetric Method	*Biological quality*	
Chloride	4500-Cl^- B. Argentometric Method	Total Coliform	9222 B. Membrane Filter Method

Table 3 Water quality standards

Parameters	Units	Water quality standards: Surface water*	Water quality standards: Tap water**
Physical and Chemical quality			
Turbidity	NTU	-	≤ 4
Colour	Pt-Co	≤ 300	≤ 15
DO	mg/L	≥ 4	-
BOD	mg/L	≤ 2	-
Nitrate	mg/L	≤ 5	≤ 50
Iron	mg/L	≤ 50	≤ 0.3
Manganese	mg/L	≤ 5	≤ 0.3
Hardness	mg/L	≤ 500	-
Chloride	mg/L	-	≤ 250
Ammonia nitrogen	mg/L	≤ 0.5	-
TDS	mg/L	≤ 1500	≤ 1500
Residual chlorine	mg/L	-	≥ 2
Biological quality			
Total Coliform	MPN/100 mL	≤ 20000	Not found

*: The guideline of World Health Organization
**: Standard of metropolitan waterworks authority

3. RESULTS AND DISCUSSION

3.1 Water Quality Assessment

3.1.1 Surface water resource quality

The results of the surface water resource quality were presented in Table 4. The results showed the parameters: turbidity, Iron, hardness, sulfate, chloride, TKN, and ammonia-N, which met the guideline of WHO and did not exceed the standard values in 100% of the samples. However, for the parameters: color, DO, manganese, nitrate, total coliform and BOD, the number of the samples that exceeded the standard limit was in a range of 8-50% of the samples. In addition, about 50% of all sampling site locations had the surface water resource quality that exceeded the standard limit for BOD. These indicated that the water resources of the urban water supply were polluted due to wastewater, urban areas, and dense population. Moreover, Nakhon Ratchasima is the second largest city in Thailand and has the poorest water resources among the other sampling cities.

3.1.2 Water quality of storage tanks

As shown in Table 5, the water quality of the storage tanks had values of the parameters: TSS, TDS, nitrate and total coliform, which met the standard of the metropolitan waterworks authority in 100% of the water samples. The water quality of the storage tanks in Nakhon Ratchasima also had limits exceeded for the parameters: color, turbidity, iron, manganese and residual chlorine. These results indicated that there might be problems with the process of water treatment. These findings were supported by the conclusion of the sub-research project that the retention time of the sedimentation process was not the proper range [3].

3.1.3 Water quality of household tap water

As shown in Table 6, the water quality of household tab water had values of the parameters: turbidity, TSS, TDS, nitrate, and total coliform, which met the standard of the metropolitan waterworks authority in 100 % of the samples. However, it was found that more than 50% of the water samples had residual chlorine less than the standard limit and had lower concentrations than the storage tanks. These results indicated that the distribution system might have problems with leakage of piping. It was supported by the conclusion of the sub-research project that found the amount of water loss from the distribution system of the water supply system which was in a range of 31-47% of water production [3]. These might affect population health.

Table 4 The percentage of water samples from water sources that did not exceed the standard

Study area	Water quality of the water source: Physical		Chemical										Biological
	Colour	Turbidity	DO	Iron	Manganese	Hardness	Sulfate	Chloride	BOD	Nitrate	Ammonia nitrogen	TKN	Total Coliform
N	91.7	100.0	83.3	100.0	91.7	100.0	100.0	100.0	58.3	91.7	100.0	100.0	83.3
C	75.0	100.0	50.0	100.0	100.0	100.0	100.0	100.0	50.0	100.0	100.0	100.0	100.0
B	100.0	100.0	75.0	100.0	100.0	100.0	100.0	100.0	50.0	100.0	100.0	100.0	100.0
S	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	50.0	100.0	100.0	100.0	100.0

Fig.2 shows 95% confidence intervals of 4 parameters: color, turbidity, coliform bacteria, and iron. Their levels and variances in the storage tanks and the tap water were significantly lower than the water sources, indicating the good efficiency of treatment plants.

Table 5 The percentage of water samples from storage tanks that did not exceed the standard

Study area	Water quality of storage tank								
	Physical		Chemical						Biological
	Colour	Turbidity	Iron	Manganese	TSS	TDS	Nitrate	Residual chlorine	Total Coliform
N	50.0	91.7	41.7	66.7	100.0	100.0	100.0	58.3	100.0
C	100.0	100.0	100.0	88.3	100.0	100.0	100.0	50.0	100.0
B	100.0	100.0	75.0	100.0	100.0	100.0	100.0	50.0	100.0
S	25.0	100.0	100.0	75.0	100.0	100.0	100.0	50.0	100.0

Table 6 The percentage of water samples of household tap water that did not exceed the standard

Study area	Water quality of household tap water								
	Physical		Chemical						Biological
	Colour	Turbidity	Iron	Manganese	TSS	TDS	Nitrate	Residual chlorine	Total Coliform
N	50.0	100.0	50.0	80.0	100.0	100.0	100.0	50.0	100.0
C	100.0	100.0	100.0	100.0	100.0	100.0	100.0	25.0	100.0
B	100.0	100.0	75.0	100.0	100.0	100.0	100.0	50.0	100.0
S	50.0	100.0	100.0	75.0	100.0	100.0	100.0	0.0	100.0

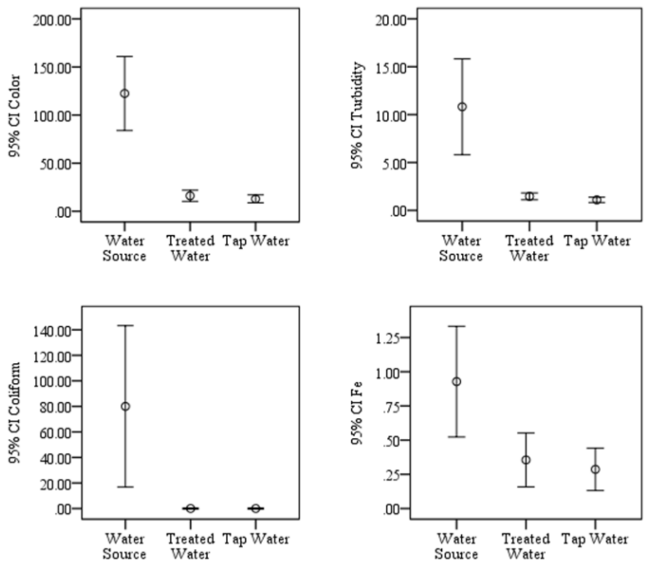

Fig.2 95% confidence intervals of water quality at the 3 locations

3.2 Efficiency of Water Supply System Plants

The efficiencies of the water supply system were calculated by the reduction of the concentration of the water qualities from the water resources to the storage tanks. Figs.3, 4 and 5 showed the efficiency of the urban water supply system in a range of 76.6-95.8% for color, 47.1-82.9% for iron and 0-68.5% for manganese. These results indicated that only Chaiyaphum urban water supply system had a manganese removal efficiency higher than 50% while the others had it lower than 25%. To assess the distribution system by comparing the water qualities between the storage tanks and the household tap water, Fig.6 showed an increase of iron concentration from the storage tanks to the household tap water. These results indicated that the distribution system of the water supply system had problems. In many types of research were included that iron pipe can corrode and leach iron into a household water system [3-5]. It was supported by the conclusion of the sub-research project that there was a potential problem of leakage in the water supply system and the maintenance of equipment [6]. The distribution systems in many cities in Thailand are a decade old. Moreover, numerous water contaminants have been reported in many cities in Pakistan, which could be the results of decades-old cast iron pipes and mixing of sewage water with potable water in the poorly managed water distribution system [7, 8].

3.3 The Authority Organization Comparison

To assess the performance of the authority organizations by comparing the water qualities of the provincial and municipal waterworks authorities, the percentages of the water samples were compared, which did not exceed the standard levels as shown in Table 7 for water sources, Table 8 for storage tanks and Table 9 for household tap water. The data of the water resource qualities were analyzed by Independent Sample Test (2-tailed), and the p-values, means, and SD of the water qualities were presented in Table 10. The results of the p-values showed that there was no significance in all parameters between the water resource qualities of the provincial and municipal waterworks authorities except the sulfate parameter. However, it was shown that many parameters had high SD values, which indicated that the data were fluctuating. When considering the mean values, it was shown that the municipal waterworks authority had better water qualities than those of the provincial waterworks authority.

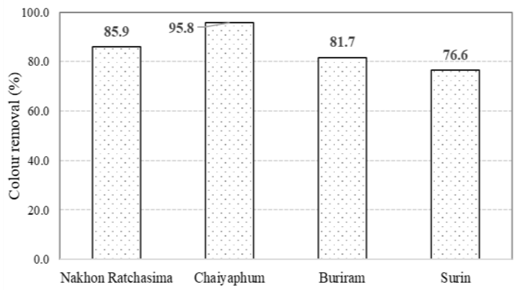

Fig.3 Removal efficiency of color in the urban water supply system

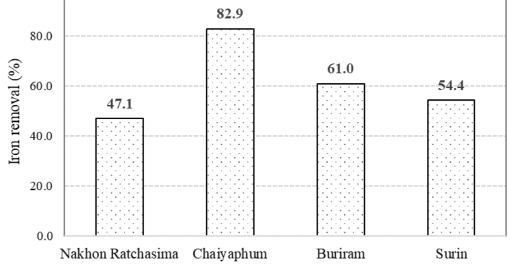

Fig.4 Removal efficiency of iron in the urban water supply system

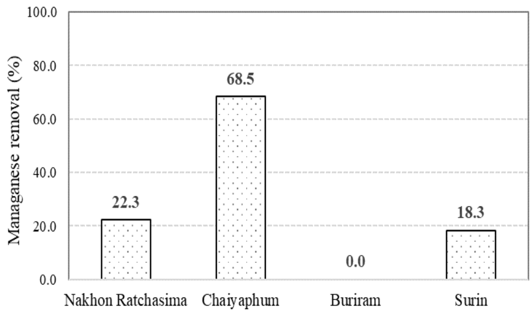

Fig.5 Removal efficiency of manganese in the urban water supply system

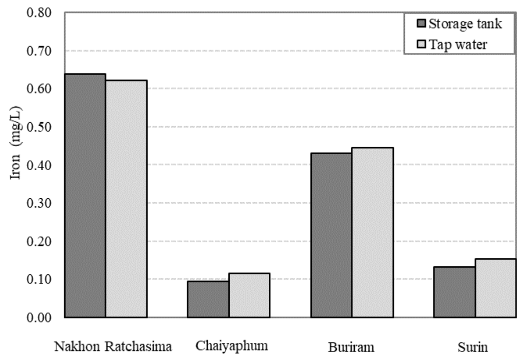

Fig. 6 The comparison of iron concentration between storage tanks and household tap water

Table 7 The percentage of water samples from water sources that did not exceed the standard compared between Provincial and Municipal waterworks authorities

Authority organization	Water quality of the water source												
	Physical		Chemical										Biological
	Colour	Turbidity	DO	Iron	Manganese	Hardness	Sulfate	Chloride	BOD5	Nitrate	Ammonia-N	TKN	Total Coliform
Provincial	90.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	50.0	100.0	100.0	100.0	90.0
Municipal	92.9	100.0	64.3	100.0	92.9	100.0	100.0	100.0	57.1	92.9	100.0	100.0	92.9

Table 8 The percentage of water samples from storage tanks that did not exceed the standard compared between Provincial and Municipal waterworks authorities

Authority organization	Water quality of storage tank								
	Physical		Chemical						Biological
	Colour	Turbidity	Iron	Manganese	TSS	TDS	Nitrate	Residual chlorine	Total Coliform
Provincial	66.7	100.0	75.0	75.0	100.0	100.0	100.0	50.0	100.0
Municipal	57.1	92.9	71.4	78.6	100.0	100.0	100.0	50.0	100.0

Table 9 The percentage of water samples of household tap water that did not exceed the standard compared between Provincial and Municipal waterworks authorities

Authority organization	Water quality of household tap water								
	Physical		Chemical						Biological
	Colour	Turbidity	Iron	Manganese	TSS	TDS	Nitrate	Residual chlorine	Total Coliform
Provincial	80.0	100.0	70.0	90.0	100.0	100.0	100.0	40.0	100.0
Municipal	58.3	100.0	75.0	83.3	100.0	100.0	100.0	25.0	100.0

The p-values, means and SDs of the water qualities of the storage tanks and the household tap water were analyzed by Independent Sample Test (2-tailed) and concluded in Tables 11 and 12 respectively. The results of the p-values showed that there was no difference in all parameters of the water qualities of the storage tanks and the household tap water between the provincial and municipal waterworks authorities. However, they had high SD values similar to water resource qualities, which indicated that the data were fluctuating. On the other hand, when considering the mean values, it was shown that the provincial waterworks authority had better values than those of the municipal waterworks authority. These results indicated that the urban water supply system which is authorized by the municipal waterworks authority produced better water qualities than the urban water supply system of the provincial waterworks authority.

Table 10 The conclusion of data analysis of water sources using Independent Sample Test (2-tailed)

Parameter	Units	Water source				p-value	Result
		Provincial		Municipal			
		Mean	SD	Mean	SD		
Colour	Pt-Co	136.9	103.1	112.2	84.1	0.524	Non-sig.
Turbidity	NTU	12.2	14.0	9.8	10.5	0.629	Non-sig.
pH	-	6.9	0.6	7.1	0.3	0.225	Non-sig.
DO	mg/L	4.9	1.3	4.3	1.7	0.347	Non-sig.
Iron	mg/L	1.1	1.4	0.8	0.5	0.371	Non-sig.
Manganese	mg/L	0.7	0.7	1.0	2.4	0.681	Non-sig.
Hardness	mg/L	40.0	35.7	55.8	35.9	0.300	Non-sig.
Sulfate	mg/L	0.01	0.01	0.02	0.02	0.019	sig.
Chloride	mg/L	50.1	78.0	44.5	60.0	0.843	Non-sig.
TSS	mg/L	29.6	24.3	31.2	26.6	0.886	Non-sig.
TDS	mg/L	288.3	352.1	262.2	229.5	0.827	Non-sig.
BOD	mg/L	3.1	1.6	2.5	1.2	0.292	Non-sig.
Nitrate	mg/L	0.6	0.5	0.9	1.6	0.623	Non-sig.
TKN	mg/L	0.3	0.3	0.2	0.3	0.801	Non-sig.

Table 11 The conclusion of data analysis of storage tanks using Independent Sample Test (2-tailed)

Parameter	Units	Storage tank				p-value	Result
		Provincial		Municipal			
		Mean	SD	Mean	SD		
Colour	Pt-Co	18.8	16.8	13.8	11.5	0.383	Non-sig.
Turbidity	NTU	1.6	0.7	1.4	1.0	0.483	Non-sig.
pH	-	6.8	1.1	7.3	0.6	0.140	Non-sig.
DO	mg/L	5.8	1.1	5.6	1.5	0.737	Non-sig.
Iron	mg/L	0.4	0.4	0.4	0.6	0.732	Non-sig.
Manganese	mg/L	0.3	0.4	0.9	2.4	0.405	Non-sig.
Chloride	mg/L	28.2	24.3	50.9	61.2	0.241	Non-sig.
TSS	mg/L	27.6	34.0	22.4	25.5	0.656	Non-sig.
TDS	mg/L	125.2	65.8	217.3	244.0	0.218	Non-sig.
Nitrate	mg/L	0.7	0.6	1.1	1.8	0.402	Non-sig.
Residual chlorine	mg/L	0.5	0.6	0.7	1.2	0.582	Non-sig.

Table 12 The conclusion of data analysis of household tap water using Independent Sample Test (2-tailed)

Parameter	Units	Household tap water				p-value	Result
		Provincial		Municipal			
		Mean	SD	Mean	SD		
Colour	Pt-Co	12.4	9.8	13.3	9.2	0.825	Non-sig.
Turbidity	NTU	0.9	0.4	1.2	0.7	0.208	Non-sig.
pH	-	7.2	0.5	7.2	0.4	0.933	Non-sig.
DO	mg/L	5.5	0.9	5.4	0.9	0.798	Non-sig.
Iron	mg/L	0.4	0.5	0.4	0.6	0.963	Non-sig.
Manganese	mg/L	0.1	0.2	0.9	2.6	0.378	Non-sig.
Chloride	mg/L	29.1	25.5	56.7	67.5	0.236	Non-sig.
TSS	mg/L	17.6	17.6	20.1	20.4	0.770	Non-sig.
TDS	mg/L	152.9	94.7	245.6	287.4	0.342	Non-sig.
Nitrate	mg/L	0.4	0.4	1.3	2.1	0.155	Non-sig.
Residual chlorine	mg/L	0.2	0.3	0.4	1.0	0.590	Non-sig.

However, in the conclusion of the sub-research project of a people satisfaction survey using questionnaires, it was found that 83.43% of people were satisfied with the quality of water and the service of water supply authority organizations [9].

4. CONCLUSION

In conclusion, the water quality of the urban water supply systems had met the water quality standards for the parameters: turbidity, TSS, TDS, Nitrate and total coliform except for color and iron due to the retention time of the sedimentation process which was not the proper range. The presence of iron in water may be responsible for its coloration and it may come from iron pipes [10,11]. This might be contributing the problem of distribution system because iron and manganese compounds in distribution systems can clog pipes and support the growth of iron and manganese bacteria. These are causing taste and odor problems of water supply [12]. Besides, there were problems with the residual chlorine in the storage tanks and the household tap water which was lower than the standard limit and might affect population health. There was no difference between the performance of the provincial and municipal waterworks authorities. The outcome of this study can support the improvement of the urban water supply systems and their authority organizations.

5. ACKNOWLEDGMENTS

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