CHAPTER 3

Results and Discussion

3.1 Sequential injection analysis (SIA) system for iron, manganese, phosphate and ammonium determination

3.1.1 Optimization of the SI-colorimetric system

Effect of some parameters of the SI-colorimetric system for determination of iron, manganese, phosphate and ammonium were investigated. For each analyte, the standard solutions in various concentrations were injected into the system for constructing of a calibration graph. The sensitivity was examined from the slope of the calibration graph. An optimum condition was selected from the condition that gave high sensitivity.

3.1.1.1 Optimization for iron determination

1) Flow rate of carrier

Effect of flow rate of the SI-colorimetric system for iron determination was studied in the range of 2 - 6 mL min⁻¹. Iron standard solutions in the concentration range 0.2 - 10.0 mg L⁻¹ were injected into the system. The results are shown in Figure 3.1. The higher flow rate provided higher sensitivity, implied that the reaction is fast, therefore, the higher flow rate resulted in low dispersion of the colored complex zone, then lead to higher sensitivity. Therefore, the flow rate of 6 mL min⁻¹ was selected for further studies.



Figure 3.1 Effect of flow rate on sensitivity for the determination of iron

Concentration of 1,10-phenanthroline

Effect of 1,10-phenanthroline concentration on iron determination by using SI-colorimetric system was investigated. Figure 3.2 shows the effect of in 1,10-phenanthroline concentration in the range of 0.1 - 2.0% w/v on sensitivity of the method. The sensitivity was stable at concentration $\geq 0.5\%$ w/v, showing that these were the excess reagent concentrations. Therefore, the concentration of 1,10-phenanthroline of 0.5% w/v was selected for further experiments.

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3) Sample volume

The volume of sample/standard for injection into SI-colorimetric system was varied from 100 - 800 μ L, while flow rate and 1,10-phenanthroline concentration were fixed at 6 mL min⁻¹ and 0.5% w/v, respectively. It was found that sensitivity drastically increase from sample volume of 100 to 600 μ L and level off at the sample volume of 700 μ L, as shown in Figure 3.3. In further experiments, the sample volume of 700 μ L was selected.

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Figure 3.3 Effect of sample volume on sensitivity for determination of iron

3.1.1.2 Optimization for manganese determination

1) Flow rate of carrier

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Effect of flow rate of carrier for manganese determination by using SI-colorimetric system was investigated by varying in the flow rate range of 1 - 4 mL min⁻¹. Slopes of each calibration graph in concentration range of 0.2 - 10.0 mg L⁻¹ are shown in Figure 3.4. From the results, flow rate of 1 and 2 mL min⁻¹ provided a similarly sensitivity and higher flow rate caused a slight decrease in sensitivity indicating that the reaction is quite slow, thus the colored product was less produced at higher flow rate. Therefore, flow rate of 2 mL min⁻¹ was selected, because this flow rate provided high sensitivity and short analysis time.

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Figure 3.4 Effect of flow rate on sensitivity for determination of manganese

2) Concentration of formaldoxime

Formaldoxime that is a reagent for forming a colored complex with Mn(II) was studied by varying its concentration from $0.05 - 0.6 \text{ mol } \text{L}^{-1}$. The reagent concentration of 0.6 mol L^{-1} was considered being excess for determination of manganese as it gave maximum sensitivity as shown in Figure 3.5. Therefore, in further experiments, 0.6 mol L^{-1} formaldoxime was used.



Figure 3.5 Effect of formaldoxime concentration on sensitivity for determination of manganese

3) Sample volume

Sample volume for manganese determination was varied from 100 - 500 μ L. The results presented in Figure 3.6, indicated that the sample volume dramatically affected to the sensitivity. The high sensitivity was achieved at sample volume 400 μ L or higher, therefore, it was selected for further studies.



Figure 3.6 Effect of sample volume on sensitivity for determination of manganese

3.1.1.3 Optimization for phosphate determination

1) Flow rate of carrier

Flow rate for the method for determination of phosphate was studied in the range of 2 - 5 mL min⁻¹. The slightly increase in sensitivity as shown in Figure 3.7. The suitable flow rate was chosen at 4 mL min⁻¹, because this flow rate provided the highest sensitivity.



Figure 3.7 Effect of flow rate on sensitivity for determination of phosphate

2) Concentration of ammonium molybdate

The orthophosphate reacts with ammonium molybdate in acidic solution to form a molybdophosphoric acid. The ammonium molybdate concentration would be studied by varying from 8 - 18 g L⁻¹. The results are shown in Figure 3.8, the concentration of ammonium molybdate drastically affected on sensitivity of the method. The lower sensitivity was observed at the higher ammonium molybdate concentration because too high concentrations of this reagent lead to precipitation of the colored product. Therefore, 10 g L⁻¹ of ammonium molybdate was selected for next experiments.



Figure 3.8 Effect of ammonium molybdate concentration on sensitivity for determination of phosphate

3) Concentration of ascorbic acid

Ascorbic acid was used as areducing agent. The molybdophosphoric acid, was occurred from orthophosphate reacts with ammonium molybdate, which was then reduced by ascorbic acid to form molybdenum blue. The concentration of ascorbic acid in range of 1.0 - 3.0% w/v was tested. The slope of each calibration graph was shown in Figure 3.9. The concentration of ascorbic acid reducing reagent of 2.5% w/v was considered being excess as the sensitivity was reached the maximum. In this work, the ascorbic acid concentration of 2.5% w/v was selected.



Figure 3.9 Effect of ascorbic acid concentration on sensitivity for determination of phosphate

4) Sample volume

The volume of sample was studied in range of 100 - 400 μ L. The sample volume affected much on sensitivity as shown in Figure 3.10, since the higher volume of sample the higher amount of the analyte was involved in the reaction. Too high sample volume caused a slight reduction in sensitivity due to less mixing of the sample and reagent zones, therefore, less product was produced. From the results, the sample volume of 300 μ L provided high sensitivity and a good SIAgram. Then, for further studies the sample volume of 300 μ L was selected.



Figure 3.10 Effect of sample volume on sensitivity for determination of phosphate

3.1.1.4 Optimization for ammonium determination

1) Flow rate of carrier

Effect of flow rate for ammonium determination was investigated in range of 2 - 5 mL min⁻¹. From the results (Figure 3.11) as similar as described above, the optimum flow rate was obtained based on the compromise between the production of the reaction product and the dispersion of it later on. Large amounts of product should be produced at low flow rate (due to longer reaction time) but the product zone would be highly dispersed at low flow rate. Therefore, the flow rate of 4 mL min⁻¹ was chosen for the next experiments.



Figure 3.11 Effect of flow rate on sensitivity for determination of ammonium

2) Concentration of sodium hypochlorite

Sodium hypochlorite was used for reacting with ammonium ion to form monochloramine in basic solution. Concentration of sodium hypochlorite was varied from 0.05 - 0.8% w/v. Figure 3.12 indicated that the highest sensitivity was obtained at excess concentration of hypochlorite reagent. In this case, the sodium hypochlorite concentration of 0.5% w/v was selected to use in further experiments, because this concentration provided enough sensitivity and better SIAgram profile.

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Figure 3.12 Effect of sodium hypochlorite concentration on sensitivity for determination of ammonium

3) Concentration of sodium salicylate

When monochloramine occurred in basic solution, it then reacted with salicylate, having sodium nitroprusside as catalyst, to produce indophenol blue (5-aminosalicylate). Therefore, the concentration of sodium salicylate was studied by varying in range of $0.1 - 0.5 \text{ mol } \text{L}^{-1}$. It was found that the sensitivity increased with the concentration of the reagents as shown in Figure 3.13. The concentration of sodium salicylate of 0.4 mol L^{-1} would be as excess concentration and gave highest sensitivity. In next experiment, the sodium salicylate concentration at 0.4 mol L^{-1} was used.



Figure 3.13 Effect of sodium salicylate concentration on sensitivity for determination of ammonium

4) Concentration of sodium nitroprusside

Sodium nitroprusside was used as catalyst that affected for amount of 5-aminosalicylate product formed. Therefore, effect of sodium nitroprusside was investigated by varying from $0.001 - 0.003 \text{ mol } \text{L}^{-1}$. The higher concentrations gave highest sensitivity (Figure 3.14) but the higher peak height of blank was observed, since sodium nitroprusside is a colored compounds was be able to absorb light at the selected wavelength. Thus, the concentration of sodium nitroprusside of 0.0015 mol L^{-1} was used in further experiments because this concentration gave enough sensitivity and good SIAgram.



Figure 3.14 Effect of sodium nitroprusside concentration on sensitivity for determination of ammonium.

5) Sample volume

Effect of sample volume for ammonium determination was tested in range of 100 - 500 μ L while flow rate and various reagent concentrations were fixed at optimum conditions. The results are illustrated in Figure 3.15, the sensitivity increased as the volume of sample increase up to 400 μ L and then the sensitivity decreased at 500 μ L indicated that the higher sample volume affected to mixing zones between sample and reagents. In this work, the volume of 400 μ L was chosen.



Figure 3.15 Effect of sample volume on sensitivity for determination of ammonium

3.1.2 Calibration graphs and analytical features

3.1.2.1 Iron and manganese

The various concentrations of iron(II) and manganese(II) were injected into proposed system. The peak height was examined and plotted with concentration of iron(II) and manganese(II). According to the study, the concentration of iron(II) and manganese(II) in the concentration range of 0.05 - 10.0 mg L⁻¹ were found to have good linearity in the concentration range of 0.2 - 10.0 mg L⁻¹ as shown in Figure 3.16 and 3.17 with a correlation coefficient of 0.9999 (y = 288.2x - 14.203) for iron and 0.9980 (y = 310.19x + 60.43) for manganese. Detection limits was calculated from LOD = 3SD equation as described in Appendix A and were found to be 0.05 and 0.16 mg L⁻¹ for iron (II) and manganese (II), respectively. Sample throughput of 20 and 13 h⁻¹ were achieved for iron and manganese.



Figure 3.17 The calibration graph of manganese determination in a linear range of $0.2 - 10.0 \text{ mgL}^{-1}$

3.1.2.2 Phosphate and ammonium

For phosphate and ammonium, the linearity was studied in concentration range of 0.1 - 10.0 mg L⁻¹. Calibration graph was plotted between concentration of phosphate and ammonium with peak height of signals. It was found that the phosphate provided a good linearity in range of 0.2 - 5.0 mg L⁻¹ as shown in Figure 3.18 with a correlation coefficient of 0.9996 (y = 494.37x - 14.413). And the ammonium in range of 0.2 - 10.0 mg L⁻¹ shown a high linearity as illustrated in Figure 3.19, with a correlation coefficient of 0.9991 (y = 817.55x + 158.2). Detection limits for phosphate and ammonium were 0.08 and 0.03 mg L⁻¹, respectively. Sample throughput of 13 h⁻¹ and 11 h⁻¹ were obtained for phosphate and ammonium, respectively.



Figure 3.18 The calibration graph of phosphate determination in a linear range of

 $0.2 - 5.0 \text{ mgL}^{-1}$



Figure 3.19 The calibration graph of ammonium determination in a linear range of $0.2 - 10 \text{ mgL}^{-1}$

3.1.3 Recoveries and comparison to standard method

Nine water samples from the Ping river were spiking of 0.5 mg L⁻¹ iron, 0.5 mg L⁻¹ manganese, 0.3 mg L⁻¹ phosphate and 0.3 mg L⁻¹ ammonium standard solutions into water samples. Recoveries were obtained in the ranges 89.1 - 103.9%, 81.8 - 102.6%, 82.1 - 118.9% and 92.1 - 115.1% for iron, manganese, phosphate and ammonium, respectively. The results are summarized in Table 3.1, indicating that the method can be applied for real sample analysis. Later on, the SI-colorimetric methods were compared with the batch spectrophotometric methods [Standard Methods for the Examination of Water and Wastewater, 1995] for the determination of iron, manganese, phosphate and ammonium in water samples as the results presented in Table 3.2. The results from both the methods were in good agreement and there are no significant differences at a confidence level of 95%. The correlation equations were obtained as follow: y = 1.1489x - 0.0822; $R^2 = 0.9810$ for ion, y = 0.9834x - 0.0362; $R^2 = 0.9868$ for manganese, y = 1.0956x + 0.0567; $R^2 = 0.9649$ for phosphate and y = 0.9867x + 0.0063; $R^2 = 0.9999$ for ammonium, respectively.

Sampling points	Samples (mg L ⁻¹)			Add (mg L ⁻¹)			Found (mg L ⁻¹)			%recovery (mg L ⁻¹)						
	Fe	Mn	PO ₄ ³⁻	NH ₄ ⁺	Fe	Mn	PO ₄ ³⁻	NH4 ⁺	Fe	Mn	PO ₄ ³⁻	NH ₄ ⁺	Fe	Mn	PO ₄ ³⁻	NH ₄ ⁺
1	0.26	0.44	1.22	0.22	0.50	0.50	0.30	0.30	0.75	0.84	1.47	0.54	97.2	81.8	83.7	107.3
2	0.24	0.57	1.27	0.18	0.50	0.50	0.30	0.30	0.72	1.02	1.62	0.45	95.7	90.0	118.9	92.1
3	0.21	0.48	1.10	0.22	0.50	0.50	0.30	0.30	0.73	0.94	1.42	0.55	103.5	93.5	109.6	109.2
4	0.19	0.45	1.27	0.18	0.50	0.50	0.30	0.30	0.64	0.93	1.55	0.47	89.1	97.3	93.1	97.8
5	0.61	0.84	0.59	0.20	0.50	0.50	0.30	0.30	1.10	1.35	0.83	0.51	98.2	102.6	83.2	102.4
6	0.62	0.69	1.41	0.13	0.50	0.50	0.30	0.30	1.14	1.18	1.74	0.42	102.8	97.8	109.7	95.2
7	0.52	0.67	0.47	0.26	0.50	0.50	0.30	0.30	1.04	1.18	0.72	0.61	102.9	101.9	82.1	115.1
8	0.45	0.76	0.66	1.54	0.50	0.50	0.30	0.30	0.94	1.19	1.01	1.82	98.7	86.9	115.2	92.1
9	0.20	0.48	0.68	3.09	0.50	0.50	0.30	0.30	0.72	0.94	1.00	3.43	103.9	92.0	106.3	112.6

Table 3.1 Recoveries of each parameter in water samples determined by the proposed system.

Table 3.2 Comparison of SI-colorimetric method and spectrometric method for determination of iron, manganese, phosphate

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and ammonium

Sampling		SIA metho	od (mg L ⁻¹)	000	Spectrophotometric method (mg L ⁻¹)			
points	Iron	Manganese	Phosphate	Ammonium	Iron	Manganese	Phosphate	Ammonium
1	$0.51_8\pm0.00_3$	$0.28_2\pm0.00_3$	$0.35_1 \pm 0.00_1$	$0.13_9\pm0.01_4$	$0.43_1 \pm 0.00_1$	$0.254\pm0.00_1$	$0.36_0\pm0.01_3$	$0.13_4\pm0.00_1$
2	$0.47_7\pm0.00_2$	$0.294\pm0.00_7$	$0.35_3\pm0.00_1$	$0.19_6\pm0.00_7$	$0.36_4\pm0.00_1$	$0.25_6\pm0.00_1$	$0.33_9\pm0.00_8$	$0.19_4\pm0.00_1$
3	$0.25_0\pm0.00_1$	$0.29_4\pm0.00_1$	$0.34_8\pm0.00_1$	ND	$0.28_3\pm0.00_1$	$0.23_6\pm0.00_1$	$0.32_6\pm0.00_8$	ND
4	$0.23_0\pm0.00_1$	$0.29_2 \pm 0.00_1$	$0.33_9\pm0.00_1$	$0.17_{1}\pm 0.00_{2}$	$0.25_7\pm0.00_1$	$0.20_1\pm0.00_1$	$0.32_8\pm0.01_4$	$0.13_8\pm0.00_1$
5	$1.21_2\pm0.00_1$	$1.04_4\pm0.01_9$	$0.35_2 \pm 0.00_1$	$0.12_7\pm0.00_5$	$1.32_8\pm0.00_1$	$0.94_9\pm0.00_1$	$0.48_2\pm0.01_1$	$0.13_4\pm0.00_1$
6	$1.24_9\pm0.00_1$	$0.58_8\pm0.00_1$	$0.39_6\pm0.00_1$	$0.23_1\pm0.00_5$	$1.42_9\pm0.00_1$	$0.57_5\pm0.00_1$	$0.49_1\pm0.01_0$	$0.21_0\pm0.00_1$
7	$1.04_5\pm0.00_1$	$0.58_6\pm0.00_3$	$0.36_0\pm0.00_1$	0.135 ± 0.005	$1.11_8\pm0.00_1$	$0.53_0\pm0.00_1$	$0.39_7\pm0.00_9$	$0.12_7\pm0.00_1$
8	$0.89_9\pm0.00_2$	$0.87_5\pm0.01_6$	$3.43_3\pm0.01_3$	$16.43_3 \pm 0.00_1$	$0.88_1\pm0.00_1$	$0.86_1\pm0.00_1$	$3.67_9\pm0.01_6$	$16.18_0 \pm 0.00_7$
9	$0.12_{0}\pm0.00_{1}$	$0.38_8 \pm 0.00_2$	$1.12_7\pm0.00_4$	$5.12_4 \pm 0.01_2$	$0.06_3\pm0.00_1$	$0.37_8 \pm 0.00_1$	$1.84_{2}\pm0.00_{8}$	$5.19_5 \pm 0.00_2$

ND = not detected

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3.1.4 Precisions

Precision of method was study by injection of standards solution at 0.5 mg L^{-1} 9 times into the system under optimum conditions. The relative standard deviations of 1.87, 0.98, 1.28 and 4.17% were obtained for iron, manganese, phosphate and ammonium, respectively. The small relative standard deviations values (< 5.0%) indicated that the proposed method had good repeatability and high precision.

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3.2 Effect of interferences

Effect of some interferences that potentially presented in natural waters on the signal of each analyte at concentration of 1 mg L⁻¹ are summarized in Table 3.2. For iron, most of cations and anions did not affect the iron analysis, except for some ions only, including Cr^{3+} , HCO_3^- that slightly impact if the concentration exceeds 5 mg L⁻¹ and CO_3^- that slightly affect if the concentration exceeds 2 mg L⁻¹. Similarly, the potential interfering ions for determination of manganese, included Co^{2+} , Cr^{3+} , Fe^{2+} , Fe^{3+} which interfere at concentrations higher than 2.0, 1.0 0.2 and 0.3 mg L⁻¹, respectively. For phosphate determination, some interfering ions consisted of Cr^{3+} , Fe^{2+} and Fe^{3+} with concentrations higher than 5.0, 0.1 and 0.1 mg L⁻¹, respectively. And finally, some ions that affected the measurement of ammonium namely Co^{2+} , Mn^{2+} , Fe^{2+} , Fe^{3+} and Γ with concentrations of ions higher than 5.0, 5.0, 0.2, 0.2 and 5.0 mg L⁻¹, respectively.

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	Iroi	n	Manga	nese	Phosph	nate	Ammonium	
Interferences	Ratio	Difference	Ratio	Difference	Ratio	Difference	Ratio	Difference
	Fe ²⁺ : Interference	(%)	Mn ²⁺ : Interference	(%)	PO ₄ ³⁻ : Interference	(%)	NH ₄ ⁺ : Interference	(%)
Na ⁺	*1:1000	0.72	1:1000	4.11	1:1000	-0.55	1:100	3.80
\mathbf{K}^+	1:1000	1.83	1:1000	3.70	1:1000	-1.99	1:100	4.58
Li ⁺	1:1000	-4.16	1:1000	3.10	1:1000	-2.51	1:1000	0.47
Ca ²⁺	1:1000	1.34	1:1000	2.72	1:1000	-3.30	1:1000	3.60
Mg^{2+}	1:1000	-4.67	1:1000	-1.83	1:800	-3.41	1:10	4.70
Zn^{2+}	1:50	-3.43	1:1000	-2.37	1:10	3.46	1:100	-1.93
Cd^{2+}	1:100	0.75	1:100	-1.08	1:100	2.97	1:100	0.63
Co ²⁺	1:30	-0.28	1:2	-0.94	1:100	4.50	1:5	-4.43
Pb^{2+}	1:100	4.72	1:100	2.29	1:100	1.46	1:10	-1.01
Cr ³⁺	1:5	3.30	1:1	4.46	1:5	-2.06	1:100	-4.92

Table 3.3 Effect of some interferences for determination of iron, manganese, phosphate and ammonium by the proposed system

Difference (%) = $\left(\frac{(B-A)}{A}\right) \times 100$; When A is a concentration of standard solutions without interference. B is a concentration of standard solutions with interference.

*1:1000 is highest ratio that tested in this study.

	Iroi	n	Manganese		Phosph	ate	Ammonium	
Interferences	Ratio	Difference	Ratio	Difference	Ratio	Difference	Ratio	Difference
	Fe ²⁺ : Interference	(%)	Mn ²⁺ : Interference	(%)	PO ₄ ³⁻ : Interference	(%)	NH4 ⁺ : Interference	(%)
Cl	1:1000	3.81	1:1000	-0.22	1:1000	1.58	1:1000	2.79
I	1:1000	1.52	1:1000	4.36	1:1000	4.62	1:5	-4.39
F⁻	1:500	-0.28	1:1000	4.06	1:5	4.18	1:10	1.54
CH ₃ COO ⁻	1:500	-3.24	1:1000	0.11	1:100	-2.10	1:500	-3.06
SO ₄ ²⁻	1:1000	4.13	1:1000	-4.67	1:1000	-2.48	1:1000	-4.76
Mn^{2+}	1:1000	3.15	± \-	I-M	1:50	-1.66	1:5	3.54
PO4 ³⁻	1:1000	-4.47	1:500	2.35	(1-5)	/ -	1:500	4.63
$\mathbf{NH_4}^+$	1:500	-4.74	1:1000	0.61	1:500	1.65	-	-
Fe ²⁺	-	-	1:0.2	2.57	1:0.1	-3.97	1:0.2	0.21
Fe ³⁺	-	-	1:0.3	3.87	1:0.1	-4.74	1:0.2	4.87

Table 3.3 (Continued)

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3.3 Application to water samples from the Ping river

Water samples collecting from the Ping river in Chiang Mai province were analyzed for iron, manganese, phosphate and ammonium contents by the proposed system. The results of each parameter in various seasons can be summarized in Table 3.3 - 3.6 and the trends of each parameter in various sampling points are shown in Figure 3.20 - 3.23.

Concentration of iron in water samples was observed in range of 0.12 - 1.64 mg L⁻¹as shown in Table 3.3 and Figure 3.20. In the upper part of Ping river iron concentration was low except at sampling point 1 in May which sample was collected in rainy day was high. After flowing through Mae Taeng district, the amount of iron was increased by affecting from Mae Taeng river (sampling point 5), which is the confluence point of Mae Ping and Mae Taeng rivers. Another sampling point that high amount of iron was observed is sampling point 8, which is wastewater of the Chiang Mai community (Mae Kha canal), it has high iron concentration that affect the quality of Mae Ping river.

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Sampling	Concentration of iron (mg L ⁻¹)								
points	February	May	August	November					
. 6 .	2000		San Stores						
1 00	$0.51_8 \pm 0.00_3$	$1.35_8 \pm 0.02_4$	$0.65_0 \pm 0.01_0$	$0.50_9 \pm 0.01_2$					
2	$0.47_7\pm0.00_2$	$0.18_7\pm0.00_4$	$0.55_9 \pm 0.00_2$	$0.29_6 \pm 0.00_2$					
3	$0.25_0\pm0.00_1$	$0.18_{1}\pm0.00_{1}$	$0.624\pm0.00_1$	$0.40_6\pm0.00_5$					
4	$0.23_0\pm0.00_1$	$0.11_7\pm0.00_2$	$0.68_6\pm0.00_1$	$0.30_4\pm0.00_7$					
5	$1.21_2\pm0.00_1$	$0.81_2 \pm 0.00_1$	$0.91_2 \pm 0.00_3$	$0.62_5 \pm 0.00_9$					
6	$1.24_9\pm0.00_1$	$0.52_8 \pm 0.00_2$	$0.56_6\pm0.00_1$	$0.56_4\pm0.00_6$					
7	$1.04_5\pm0.00_1$	$0.42_2\pm0.00_1$	$0.79_0 \pm 0.00_3$	$0.39_3\pm0.00_5$					
8	$0.89_9\pm0.00_2$	$0.63_1 \pm 0.00_6$	$1.64_1 \pm 0.00_2$	$1.07_2\pm0.00_4$					
9	$0.12_0\pm0.00_1$	$0.20_{6}\pm 0.00_{1}$	$0.69_2 \pm 0.00_1$	$0.79_7\pm0.00_3$					

Table 3.4 Concentrations of iron in water samples determined by the proposed system

From the manganese analysis of water samples, it was found that concentration of manganese was observed in the range of $0.28 - 1.84 \text{ mg L}^{-1}$ as summarized in Table 3.4. For Thailand, concentration of manganese in surface water should not exceed 1 mg L⁻¹ [Pollution Control Department of Thailand]. The results found that, the amount of manganese in water samples mainly withMae Taeng (sampling point 5) has high manganese content when entering into the Ping river, as a result, the Mae Ping river has an increase amount of manganese. Figure 3.21 shows the trend of the amount of manganese in each season, which is similar except in rainy season (August), since soil erosion which has input manganese compound into river.

 Table 3.5 Concentrations of manganese in water samples determined by the proposed system

Sampling	Concentration of manganese (mg L ⁻¹)								
points	February	May	August	November					
	1905	Teres .	1 200	×					
1	$0.28_2 \pm 0.00_3$	$1.83_6 \pm 0.01_6$	0.605 ± 0.002	$0.43_6 \pm 0.00_5$					
2	$0.294\pm0.00_7$	$0.29_2 \pm 0.00_2$	$0.39_9\pm0.00_4$	$0.38_2\pm0.00_4$					
3	$0.29_4\pm0.00_1$	$0.27_7 \pm 0.01_2$	$0.45_2\pm0.00_4$	$0.40_0 \pm 0.00_2$					
4	$0.29_2\pm0.00_1$	$0.18_5\pm0.00_2$	$0.52_{1}\pm0.00_{2}$	$0.34_1 \pm 0.00_2$					
5	$1.04_4\pm0.01_9$	$0.71_0 \pm 0.00_2$	$1.17_8\pm0.00_7$	$0.90_7\pm0.00_2$					
6	$0.58_8\pm0.00_1$	$1.11_0\pm0.01_0$	$0.51_0 \pm 0.00_1$	$0.71_6\pm0.02_4$					
7	$0.58_6\pm0.00_3$	$0.70_0 \pm 0.00_6$	$0.58_{6}\pm 0.00_{2}$	$0.61_5\pm0.00_3$					
8 8 8	$0.87_5 \pm 0.01_6$	$0.73_8\pm0.00_4$	$1.03_0 \pm 0.00_2$	$1.02_9\pm0.00_7$					
9 Co	$0.38_8\pm0.00_2$	$0.337\pm0.00_2$	$0.54_7\pm0.00_6$	$0.68_8\pm0.00_3$					
A	l rig	hts r	eserv	e d					

For phosphate analysis of water samples, it was found that the concentration of phosphate was observed in the range of $0.34 - 4.69 \text{ mg L}^{-1}$. Figure 3.22 indicates that quality of water in the Ping river after sampling point 8 affected by the water discharged from Mae Kha canal, is waste water discharges from community, which have high amount of detergent. As a result, phosphate content exceeds the permissible limit of 2 mg L⁻¹ [Pollution Control Department of Thailand], which increased the phosphate content at sampling 9 of Ping river.

Concentration of phosphate (mg L⁻¹) Sampling points February May August November 1 $0.35_1 \pm 0.00_1$ $0.43_2 \pm 0.00_1$ $0.40_1 \pm 0.00_1$ $0.37_1 \pm 0.00_3$ 2 $0.35_3 \pm 0.00_1$ $0.35_9 \pm 0.00_1$ $0.35_9 \pm 0.00_1$ $0.38_3 \pm 0.00_2$ 3 $0.34_8\pm0.00_1$ $0.35_6 \pm 0.00_1$ $0.35_8\pm0.00_3$ $0.37_8 \pm 0.00_2$ $0.36_5\pm0.00_1$ 4 0.339 ± 0.001 $0.34_8 \pm 0.00_2$ $0.38_7\pm0.00_2$ 5 $0.35_2 \pm 0.00_1$ $0.34_9 \pm 0.00_1$ $0.35_6 \pm 0.00_1$ $0.39_1 \pm 0.00_3$ $0.39_6 \pm 0.00_1$ $0.34_4 \pm 0.00_1$ $0.36_4\pm0.00_1$ 6 $0.37_9 \pm 0.00_3$ 7 $0.36_0 \pm 0.00_1$ $0.34_6 \pm 0.00_1$ $0.36_8\pm0.00_1$ $0.38_1 \pm 0.00_2$ 8 $4.48_0 \pm 0.00_7$ $3.43_3 \pm 0.01_3$ $4.69_3 \pm 0.01_9$ $2.84_9\pm0.00_4$ 9 $1.12_7 \pm 0.00_4$ $0.84_6 \pm 0.00_4$ $0.45_6 \pm 0.00_1$ $0.39_7 \pm 0.00_3$

 Table 3.6 Concentrations of phosphate in water samples determined by the proposed system

Similarly, from ammonium analysis of water samples, it was found that the concentration of ammonium was observed in the range of $0.13 - 16.77 \text{ mg L}^{-1}$. The Ping river has been greatly affected by the waste water from Chiang Mai community as indicated by very high amount of ammonium at sampling point 8 and 9. From Figure 3.23, it should be noticed that sampling point 8 is wastewater of the community before releasing into the river, have high ammonium concentration to render amount of ammonium in the Ping river has increased, which exceeded the allowable limit of 0.5 mg L⁻¹[Pollution Control Department of Thailand], indicating that, community wastewater affect the amount of ammonium in the Ping River significantly.

 Table 3.7 Concentrations of ammonium in water samples determined by the proposed

S. / ______

Sampling	Concentration of ammonium (mg L ⁻¹)								
points	February	May	August	November					
1	$0.13_9 \pm 0.01_4$	$1.60_6 \pm 0.01_0$	$2.36_3 \pm 0.01_3$	$0.24_1 \pm 0.00_3$					
2	$0.19_6\pm0.00_7$	$0.30_7\pm0.00_6$	$0.27_4\pm0.00_1$	$0.18_5\pm0.00_1$					
3	ND	$0.29_1 \pm 0.01_0$	$0.23_6\pm0.00_4$	$0.21_5\pm0.00_3$					
4	$0.17_{1}\pm0.00_{2}$	$0.21_0 \pm 0.00_3$	$0.21_9\pm0.00_8$	$0.15_0\pm0.00_3$					
5	$0.12_7\pm0.00_5$	$0.88_0 \pm 0.00_2$	$0.38_7\pm0.00_4$	$0.17_9\pm0.00_1$					
6	$0.23_1\pm0.00_5$	$0.35_6\pm0.00_5$	$0.33_8\pm0.00_7$	$0.26_4\pm0.00_8$					
7 82	0.135 ± 0.005	$0.38_0\pm0.01_4$	0.437 ± 0.017	$0.35_9\pm0.00_1$					
8	$16.43_3 \pm 0.00_1$	$16.77_2 \pm 0.01_7$	$11.82_5 \pm 0.02_0$	$13.71_7 \pm 0.00_1$					
9 00	$5.12_4\pm0.01_2$	$1.10_2 \pm 0.00_6$	$3.52_7\pm0.00_3$	$1.36_3\pm0.00_2$					
A	ll rig	hts ro	eserv	e d					

system

