CHAPTER 4
GROUNDWATER QUALITY

The study of groundwater quality involved a description of the occurrence of the various constitutes in groundwater and the relation of these constituents to water uses. Therefore, groundwater quality data give important information to the geologic history of rocks and indications of groundwater recharge, discharge, movement, and storage (Walton, 1970).

The groundwater samples were collected from 17 groundwater wells, including 4 groundwater wells in the study area, 8 groundwater wells in Samet Nua Sub-district, and 5 groundwater wells in Tha Thong Lang Sub-district. The location of the collected groundwater samples are shown in Figure 4.1 and Table 4.1. These groundwater samples were analyzed for various chemical and physical parameters by Department of Groundwater Resources. These parameters include pH, electrical conductivity, total hardness, total dissolved solids, and important cations such as calcium, magnesium, sodium, and potassium as well as anions such as carbonate, bicarbonate, chloride, nitrate, sulphate, and fluoride. The chemical and physical properties of groundwater samples are shown in Table 4.2.

4.1 Groundwater Chemistry

Groundwater is not pure water because it always contain dissolved mineral ions. The type and concentration of these dissolved minerals can affect the usefulness of groundwater.

Groundwater chemistry was considered in terms of chemical and physical characteristics, which determine its usefulness for domestic, agricultural, and industrial water supplies. Chemical analysis of groundwater included determination of the concentration of water chemical constituents and pH. Electrical conductivity (EC) is evaluated by physical analysis.

Reliability of the groundwater analysis can be considered from cation-anion balance (Δ %) that is defined by:

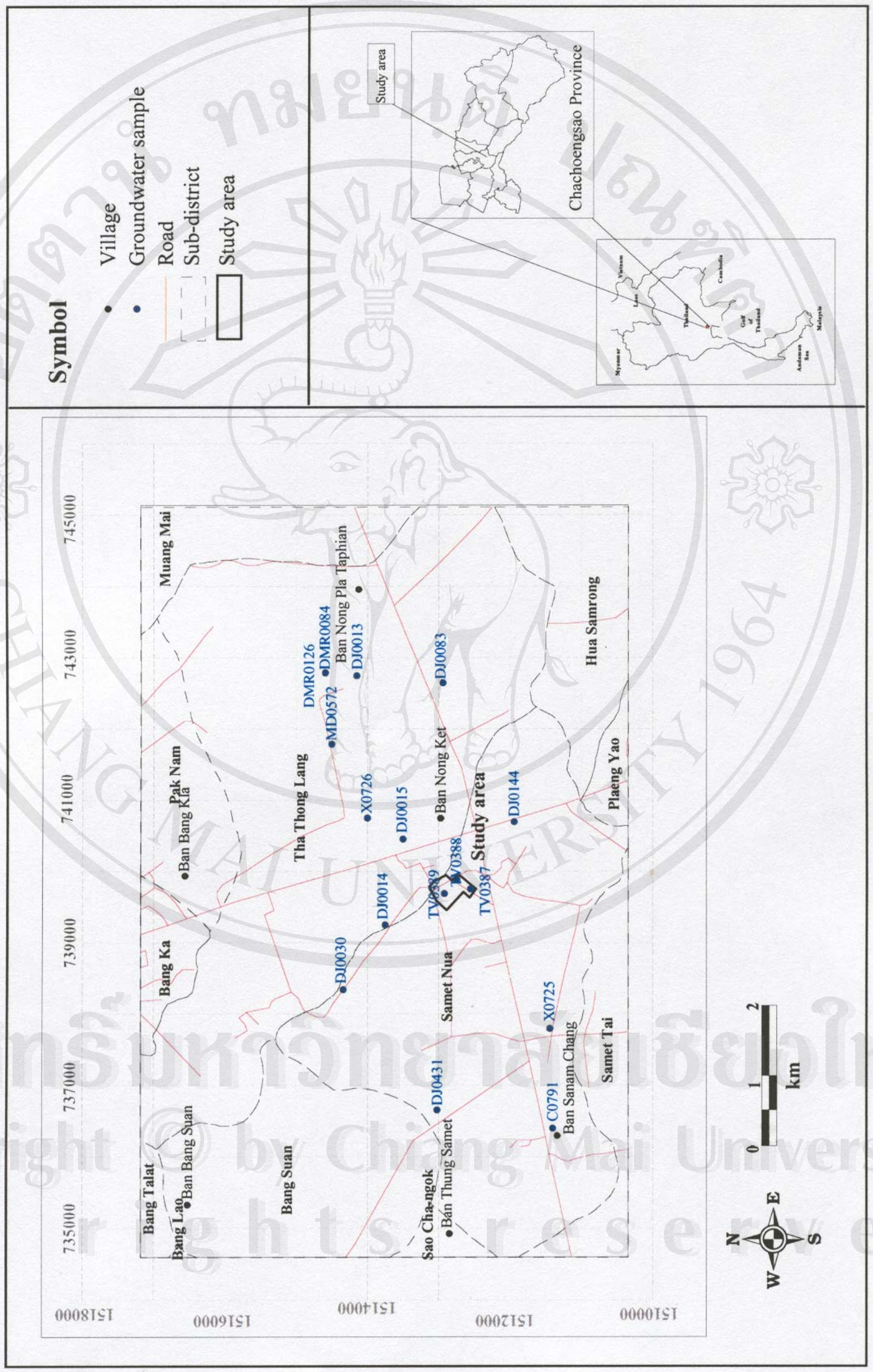

Figure 4.1 Groundwater sampling location.

Table 4.1 Groundwater sampling location.

Well No.	Grid		Depth	Elevation
	UTM_E	UTM_N	(m)	(m)
C0791	736400	1511400	105	3
DJ0013	742750	1514150	75	4
DJ0014	739250	1513750	105	3
DJ0015	740450	1513500	84	4
DJ0030	738340	1514340	105	2
DJ0083	742650	1512940	111	4
DJ0144	740696	1511940	139.5	3
DJ0431	736654	1513023	76	2
DMR0084	742790	1514592	36	3
DMR0126	742790	1514590	48	3
MD0572	741790	1514500	72	4
X0725	737790	1511440	99	2
X0726	740750	1514000	99	4
TV0387	739751	1512553	178	2
TV0388	739885	1512746	180	2
TV0389	739687	1512919	168	2
TV0390	739768	1512834	120	2

Table 4.2 Analytical data of groundwater samples.

Well no.	Grid		Depth	Date	pH	EC[a]	TH[b]	TDS[c]	Cation				Anion					F	Fe	Mn	Δ %
	UTM_E	UTM_N	(m)	analyzed					Ca	Mg	Na	K	CO_3	HCO_3	Cl	NO_3	SO_4				
C0791	736400	1511400	105	27/11/1990		1,070	94								88	0.8			14		-
				06/07/1992	8.5	929	70	496	16	7.2	190	1.6	26	296	110	0	15	1.2	0.2	0.1	2.99
DJ0013	742750	1514150	75	23/06/1992		1,800	348	1,170							495	2			50		-
				27/08/2003	7.4	4,280	1,000	2,780	360	54	380	1	0	180	1,200	0.2	0	0.2	13	0.3	2.84
				11/12/2003	7.7	4,270	1,000	2,780							1,200	<2.2	<10	<0.4	17	0.3	-
DJ0014	739250	1513750	105	15/04/1986	7.3	10,020	2,750	7,725	5,000	3,650	1,058	5.5	0	102	2,460	0	25	0.7	3.6	0.02	78.54
				23/06/1992		3,270	400	2,125							810	0.2			12		-
				20/08/1992	7.5	772	380	458	114	23	25	0.8	0	447	20	0.1	4	0.9	0.4	0	4.27
DJ0015	740450	1513500	84	15/04/1986	7.5	11,260	1,970	7,680	2,720	3,140	1,584	19	0	82	3,560	15	90	0.1	6.1	0.5	63.36
				23/06/1992		1,420	33	923							217	0.2			2.4		-
DJ0030	738340	1514340	105	10/04/1992	7.7	511	250	300	65	21	18	7	0	320	14	0	4	0.1	8.7	0.3	1.79
DJ0083	742650	1512940	111	27/08/2003	8.5	905	66	588	16	6.4	170	1.1	1	411	84	0	0	1.8	0.2	0	-2.19
				11/12/2003	8.4	908	66	590							80	<2.2	<10	1.7	0.2	0.1	-
DJ0144	740696	1511940	139.5	27/0820/03	7.7	2,150	250	1,400	88	6.4	290	1.2	0	204	540	0.5	0	0.3	0.6	0.2	2.83
				17/10/2003	8.1	2,840	420	1,850							740	<2.2	180	<0.4	0.2	0	-
				11/12/2003	7.7	2,920	450	1,900							760	<2.2	18	<0.4	0.2	0.7	-
DJ0431	736654	1513023	76	19/04/1999		2,650	490	1,720							600	2.9		1.5	4		-
				27/08/2003	7.0	4,660	660	3,030	150	71	690	1.3	0	164	1,200	0	260	0.3	4.9	4.4	1.66
				11/12/2003	7.6	5,960	810	3,870							1,700	<2.2	180	<0.4	11	6.2	-
				14/06/2004	7.8	2,590	430	1,680	84	54	380	5.6	0	248	540	<2.2	320	<0.4	0.3	1.8	-1.35
DMR0084	742790	1514592	36	01/07/1983	8.4	1,550	153		39	14	237	4.7	26	255	297	0	24	0.4	0.08	0.1	-1.45
				18/08/1983	8.2	1,620	191	890	49	17	262	5.1	0	250	372	0	26	0.4	12	0	0.78
				21/03/1990		1,030	183								206	0.3			0.3		-

Table 4.2 (Continued).

Well no.	Grid		Depth	Date	pH	EC[a]	TH[b]	TDS[c]	Cation				Anion					F	Fe	Mn	Δ%
	UTM_E	UTM_N	(m)	analyzed					Ca	Mg	Na	K	CO_3	HCO_3	Cl	NO_3	SO_4				
DMR0126	742790	1514590	48	18/02/1981	7.3	1,250	220	732	72	9.7	177	4.3	0	373	202	0	13	0.2	24		0.48
				11/12/1984	8.1	630	81	412	17	9.4	122	3.9	0	318	39	0	36	0.4	0.8	0.01	-0.24
MD0572	741790	1514500	72	27/11/1990		634	138									0.1			49		-
				11/12/2003	8.4	600	86	390							18	<2.2	<10	<0.4	0.2	0	-
X0725	737790	1511440	99	12/10/1989		904	118								89	0			3.7		-
				12/01/1994		804	94	523							85	0			0.1		-
				27/08/2003	8.5	934	66	607	16	6.3	170	28.1	1	423	84	0	0	1.8	0.1	0	0.50
				17/10/2003	8.2	940	84	611							82	<2.2	<10	1.8	0.1	0	-
				11/12/2003	8.8	900	53	585							80	<2.2	<10	1.7	0.1	0	-
X0726	740750	1514000	99	15/01/1990		266	105								11	2.2			2.8		-
				26/03/1991		481	70								13	0.1			0.2		-
				27/08/2003	7.7	2,950	450	1,920	160	13	420	37.8	0	401	540	0.3	310	0.5	2.9	0	0.04
				11/12/2003	7.9	3,000	460	1,950							560	<2.2	310	0.5	3.6	0.1	-
TV0387	739751	1512553	178	17/10/2003	8.5	775	24	504							50	<2.2	<10	1.3	10	0	-
				10/10/2004	8.4	648	27	421	9.8	0.6	130	1.1	42	268	37	0	0	1.4	0	0	-4.77
TV0388	739885	1512746	180	17/10/2003	7.9	728	48	473							74	<2.2	12	1.5	0.4	0	-
				10/10/2004	8.8	578	31	349	12	0.4	120	0.8	47	190	60	0	0	1.5	0.2	0	-4.09
TV0389	739687	1512919	168	17/10/2003	8.3	665	35	432							86	<2.2	<10	2.9	0.8	0.1	-
TV0390	739768	1512834	120	17/10/2003	8.0	1,900	200	1,240							380	<2.2	49	1.7	1.2	0.2	-
				10/10/2004	7.8	1,340	150	792	41	11	260	2	0	331	340	0	10	1.9	0.1	0.1	-3.21

Remark: All parameter are expressed in mg/l, except pH in unit and EC in μS/cm.
[a]EC Elctrical conductivity; [b]TH Total hardness; [C]TDS Total dissolved solid; [d]Δ % percentage of cation-anion balance

$$\text{Cation-anion balance } (\Delta \%) = \frac{(\text{Total cations} - \text{Total anions}) \text{ X100}}{\text{Total dissolved ions}} \quad \text{(Eq. 4.1)}$$

Where all concentration are expressed in milliequivalents per liter (meq/l))

Total dissolved ions = Total cations + Total anions

Total cations = $Na^{+} + K^{+} + Ca^{2+} + Mg^{2+}$

Total anions = $CO_3^{-} + HCO_3^{-} + Cl^{-} + NO_3^{-} + SO_4^{2-}$

The cation-anion balance is thus expressed as percentage of the total ion concentration. Positive error indicate cation excess when negative error indicate anion excess. Cation-anion balance are caused by the analytical errors of the individual parameters, and the fact that not all possible ions are commonly measured. The groundwater analysis are reliable if cation-anion balance is less than 10 %. From Table 4.2, most groundwater samples, with complete analysis, have cation-anion balance less than 10 %, indicating that the analysis are reliable. Some analysis are greater than 10 % and therefore are not used for further consideration.

The Stiff diagram is used for comparison between water from difference sources that show the chemical character of the groundwater according to absolute concentration. Stiff diagram is created from four parallel horizontal axis extending on either side of a vertical zero axis. Cations are plotted in milliequivalent per liter on the left of the zero axis, one to each horizontal axis, and anions are plotted on the right (Fetter, 1988).

For the study area and its adjacent, the contrast in the chemical character of water is more apparent from the Stiff diagram (Figure 4.2). RockWorks99 software from Rockware Inc. was used in plotting the Stiff diagram. Most groundwater from the study area and its adjacent are similar in chemical content, and that sodium and calcium are dominated cations and chloride are dominated anions.

4.1.1 Physical characteristics

From Table 4.2 and in general, the pH values of groundwater in the study area and its adjacent range from 7.0 to 8.8, indicating an alkaline type of groundwater.

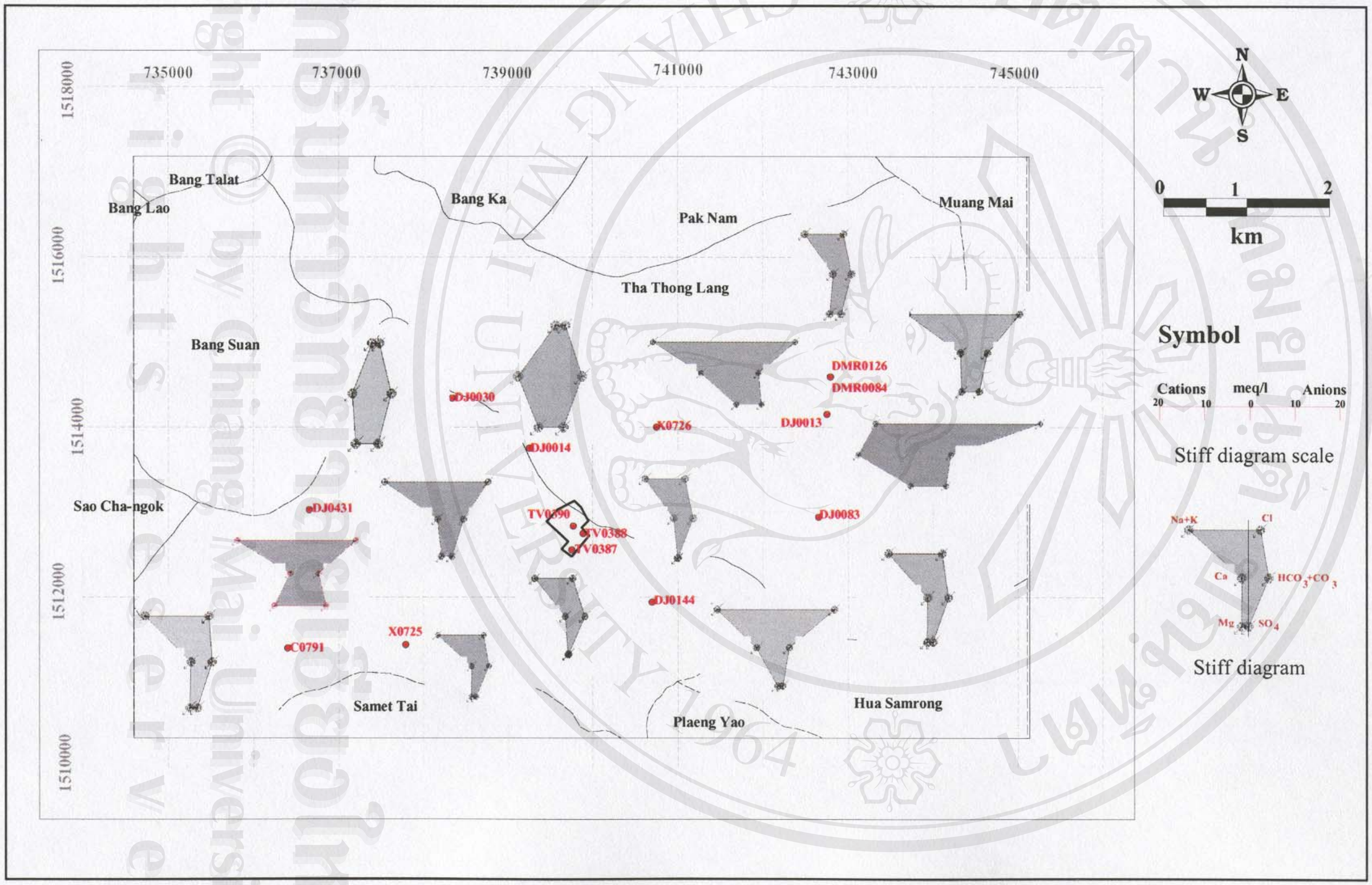

Figure 4.2 Stiff diagram in the study area and its adjacent.

The electrical conductivity (EC) values range from 266 to 5,960 µS/cm. The large variation in EC is probably attributed to anthropogenic activities and geochemical process prevailing in the area.

Total dissolved solids (TDS) in the area range from 300 to 3,870 mg/l. Table 4.3 shows groundwater classification based on total dissolved solids. The groundwater in the area fall under fresh water to brackish types of water.

Total hardness (TH) as $CaCO_3^-$ range from 24 to 1,000 mg/l. Table 4.4 shows groundwater classification based on total hardness. The groundwater fall most under very hard water. Some groundwater fall under soft water. Hardness caused by calcium and magnesium is usually indicated by precipitation of soap scum and the need for excess use of soap to achieve cleaning. Water for domestic use should not contain more than 80 mg/l total hardness.

In the study area, the pH values range from 7.8 to 8.8, indicating an alkaline type of groundwater. The electrical conductivity range from 578 to 1,340 µS/cm. Total dissolved solids in the study area range from 349 to 792 mg/l and can be considered as fresh water type (Table 4.3). Total hardness range from 24 to 150 mg/l and can be considered as soft water to moderately hard water. Water with TH greater than 80 mg/l generally is not suitable for domestic purpose, because it coagulates soap lather.

4.1.2 Cation concentration

Calcium (Ca^{2+}) and sodium (Na^+) are generally the major cations in the study and its adjacent area, however, potassium (K^+) is dominant in some groundwater samples. Calcium concentration range from 16 to 360 mg/l and sodium concentration range from 18 to 690 mg/l. High concentration of Na^+ and Ca^{2+} in the groundwater is attributed to cation exchange among minerals. Magnesium concentration range from 0.6 to 71 mg/l. The concentration of potassium range from 0.8 to 37.8 mg/l. The major source of magnesium and potassium in groundwater is considered to be due to ion exchange in rocks and soil by water.

In the study area, calcium and sodium are generally the major cation. Concentration of calcium range from 9.8 to 41 mg/l. Calcium sources in alluvial and unconsolidated materials consist primarily of the various minerals in the rocks and

Table 4.3 Groundwater classification based on total dissolved solids (from Freeze and Cherry, 1979).

Type of water	**TDS (mg/l)**
Fresh water	0-1,000
Brackish	1,000-10,000
Saline	10,000-100,000
Brine	>100,000

Table 4.4 Groundwater classification based on total hardness (from Todd, 1980).

Classification	**TH (mg/l)**
Soft water	0-75
Moderately hard water	75-150
Hard water	150-300
Very hard water	>300

soil fractions in these deposits (Bouwer, 1978). Sodium concentration range from 120 to 260 mg/l. Shale and clay layer often yield water with a relatively high sodium content (Bouwer, 1978). Magnesium concentration range from 0.4 to 11 mg/l. Concentration of potassium in the study area range from 0.8 to 2 mg/l.

4.1.3 Anion concentration

Chloride (Cl^-) is the dominant anion in the study and its adjacent area. Chloride concentration range from 10 to 1,700 mg/l, generally with low concentration. Groundwater containing significant amounts of chloride also tend to have high amounts of sodium, indicating the possibility of content with water of marine origin (Bouwer, 1978). Bicarbonate (HCO_3^-) range from 82 to 447 mg/l. The source of bicarbonate in the groundwater are derived from the carbonate dioxide in the atmosphere, carbon dioxide in the soil, and solution of carbonate rocks (Davis and DeWiest, 1966). Nitrate concentration (NO_3^-) range from 0.1 to 2.9 mg/l. Sulfate concentration range from 4 to 320 mg/l. Concentration of iron range from 0.1 to 50 mg/l. From oxidation-reduction or redox reaction, the ferrous iron oxidation to ferric iron, giving a reddish-brown color to the water. The concentration of fluoride range from 0.1 to 2.9 mg/l. Fluoride is one of the main trace elements in groundwater, which generally occurs as a natural constituent. Bed rock containing fluoride minerals is generally responsible for high concentration of this ion in groundwater (Subramani *et al.*, 2005). High fluoride caused mottling of tooth enamel.

In the study area, the concentration of chloride range from 10 to 380 mg/l. High chloride concentration may be caused by leaching of saline residues in the soil because of climate condition and anthropogenic activity. Concentration of bicarbonate range from 190 to 331 mg/l. Water with high bicarbonate concentration, if used for sprinkler irrigation, may cause white deposits on fruits and leaves, which is undesirable. Nitrate concentration is less than 2.2 mg/l. Sulfate and fluoride concentration range from 10 to 49 mg/l and 1.3 to 2.9 mg/l, respectively. Iron concentration range from 0.1 to 10 mg/l.

4.2 Hydrochemical facies

Hydrochemical facies is used to explain the bodies of groundwater, in an aquifer, that differ in their chemical composition. The facies are a function of the lithology, solution kinetic, and flow patterns of the aquifer (Fetter, 1988).

Hydrochemical facies is the relative concentrations of the major cations (Ca^{2+}, Na^{+}, Mg^{2+}, and K^{+}) and anions (CO_3^{-}, HCO_3^{-}, Cl^{-}, and SO_4^{-}). Cations are plotted on the left triangle and anions on the right triangle that represented by trilinear diagram or Piper diagram. All concentration are in milliequivalent per liter (meq/l) or equivalent per million (epm) unit. Hydrochemical facies represent the observed spatial pattern of solute concentrations in groundwater which resulted from the chemical processes operating, rock types, and the flow paths in the region. Piper diagram are very useful to determine chemical relationships in groundwater in more definite terms than is possible with other plotting method. Piper diagram is used to classify the groundwater based on the basic geochemical character of the constituent ionic concentrations. Hydrochemical facies can be classified on the basic of the dominant ions in the facies by means of Piper diagram (Figure 4.3).

The classification of hydrochemical facies of all the groundwater samples in the study and its adjacent area were analyzed using RockWorks99 software from Rockware Inc.. The analytical values obtained from the groundwater samples, and plotted on Piper diagram (Figure 4.4), reveal that the major cation are sodium and calcium, and anion are chloride and bicarbonate. Sodium may be derived from sedimentary rocks that contain feldspar and clay. Calcium may be derived from cation exchange among minerals. Chloride and bicarbonate are the dominant anion. Chloride may be derived from leaching of saline residues and bicarbonate may be derived from sewage and various human activities. In general, groundwater in the study area and its adjacent can be classified into 5 groups of facies, as follows (Table 4.5): 1 sample of Na-HCO_3-Cl-SO_4 facies, 1 sample of Ca-Na-Cl-SO_4 facies, 2 samples of Ca-Mg-HCO_3-Cl-SO_4 facies, 5 samples of Na-Ca-Cl-SO4-HCO3 facies, and 5 samples of Na-Ca-HCO_3-Cl-SO_4 facies.

In the study area, groundwater can be classified into 3 groups, as follows: 1 sample of Na-HCO_3-Cl-SO_4 facies, 1 sample of Na-Ca-Cl-SO_4-HCO_3 facies, and 1 sample of Na-Ca-HCO_3-Cl-SO_4 facies.

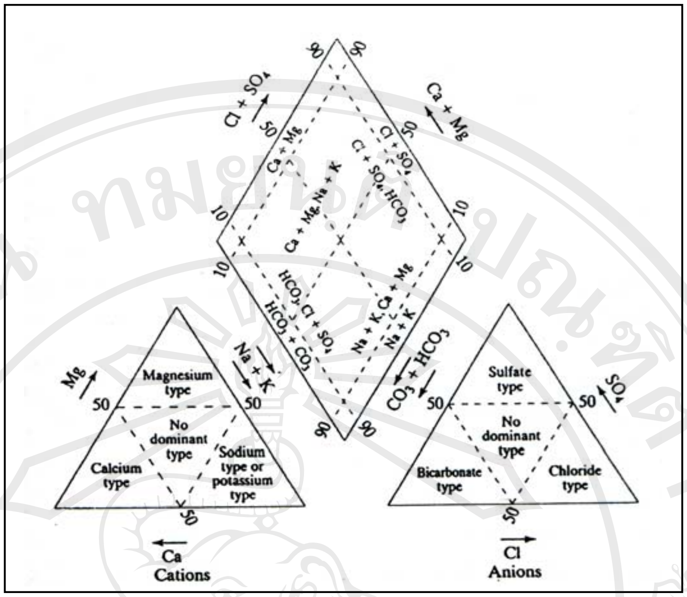

Figure 4.3 Hydrochemical facies using Piper diagram (from Fetter, 1988).

Table 4.5 Hydrochemical facies of groundwater samples.

Well No.	**Hydrochemical facies**
C0791	Na-Ca-HCO_3-Cl-SO_4
DJ0013	Ca-Na-Cl-SO_4
DJ0014	Ca-Mg-HCO_3-Cl-SO_4
DJ0030	Ca-Mg-HCO_3-Cl-SO_4
DJ0083	Na-Ca-HCO_3-Cl-SO_4
DJ0144	Na-Ca-Cl-SO_4-HCO_3
DJ0431	Na-Ca-Cl-SO_4-HCO_3
DMR0084	Na-Ca-Cl-SO_4-HCO_3
DMR0126	Na-Ca-HCO_3-Cl-SO_4
X0725	Na-Ca-HCO_3-Cl-SO_4
X0726	Na-Ca-Cl-SO_4-HCO_3
TV0387	Na-HCO_3-Cl-SO_4
TV0388	Na-Ca-HCO_3-Cl-SO_4
TV0390	Na-Ca-Cl-SO_4-HCO_3

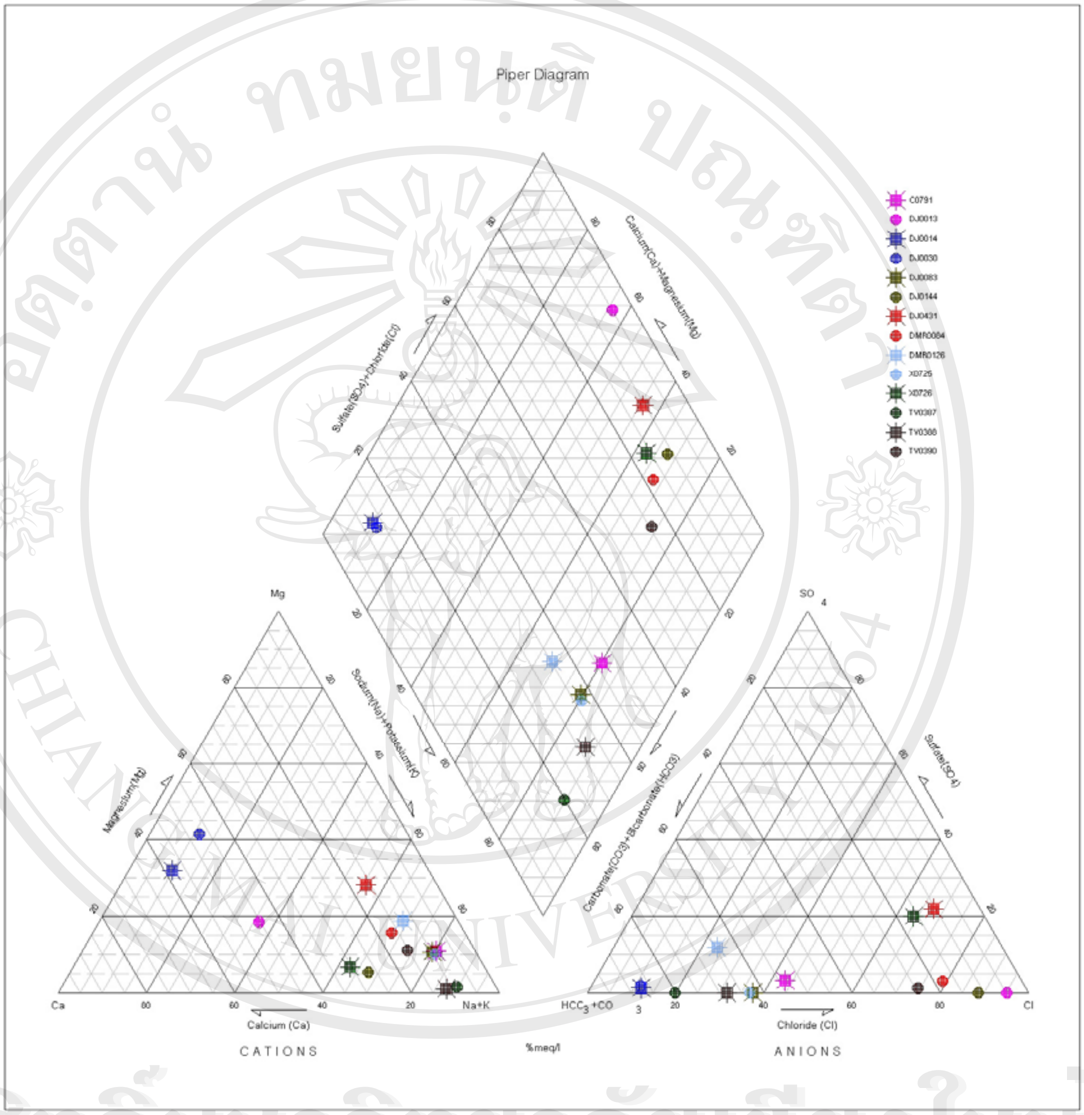

Figure 4.4 Hydrochemical facies of groundwater in the study and its adjacent area.

4.3 Relation of groundwater quality to uses

Most interpretation of groundwater quality data are used to determine if the water is satisfactory in quality for a proposed use. Whether a groundwater of a given quality is suitable for a particular purpose depends on standards of acceptable quality for that use. Quality limits of water supplies for drinking water, industrial, and agricultural used are different and will be later discussed.

4.3.1 Domestic use

Drinking water standards are based on two criteria (Davis and DeWiest, 1966): (1) the presence of objectionable tastes, odors, or colors, and (2) the presence of substances with adverse physiological effects. The drinking water standard of Thailand and groundwater quality standard for drinking purpose, controlled by the Ministry of Industry in 1978, are shown in Table 4.6 and Table 4.7, respectively. The permissible limits prescribed by World Health Organization (WHO) for drinking purpose (Subramani *et al.,* 2005) is shown in Table 4.8. These tables show the most desirable limits and maximum allowable limits of various parameters. In general, the concentration of dominate cation such as sodium and calcium and dominate anion such as chloride and fluoride are within the maximum allowable limits for drinking except some groundwater samples. Moreover, total dissolved solids and total hardness are within the maximum allowable limits of drinking purpose. Groundwater in the study area and its adjacent are generally suitable for domestic, after reduction or removable of some undersideable parameters, especially sodium, calcium, chloride, fluoride, total dissolved solids, and total hardness. Various methods to remove contamination in drinking water are shown in Table 4.9.

Total dissolved solids in the study area and its adjacent range from 300 to 3,870 mg/l, indicating fresh to brackish water. Most of groundwater samples are within the maximum permissible limit for drinking water of WHO and drinking water quality standards of Thailand. The total dissolved solids map (Figure 4.5) was prepared using the most desirable (500 mg/l) and maximum allowable (1,500 mg/l) as limits criteria. The map shows two third of the area is below the maximum permissible limit. Total hardness range from 24 to 1,000 mg/l. Most groundwater samples are below the maximum allowable limits at 500 mg/l. Sodium is unstable if it exceeds the

Table 4.6 Drinking water quality standards of Thailand (from Notification of the Ministry of Industry, No. 332, B.E. 2521, 1978).

Properties	Parameters	Units	Standard	
			Maximum acceptable concentration	Maximum allowable concentration
Physical	1.Color	Platinum-Cobalt (Pt-Co)	5	15
	2.Taste	-	-	-
	3.Odour	-	-	-
	4.Turbidity	Silica scale unit (SSU)	5	20
	5.pH	-	6.5-8.5	9.2
Chemical	1.Total solid	mg/l	500	1,500
	2.Iron (Fe)	mg/l	0.5	1.0
	3.Manganese (Mn)	mg/l	0.3	0.5
	4.Iron & Manganese (Fe & Mn)	mg/l	0.5	1.0
	5.Copper (Cu)	mg/l	1.0	1.5
	6.Zinc (Zn)	mg/l	5.0	15.0
	7.Calcium (Ca)	mg/l	75[b]	200
	8.Magnesium (Mg)	mg/l	50	150
	9.Sulphate (SO_4)	mg/l	200	250[c]
	10.Chloride (Cl)	mg/l	250	600
	11.Fluoride (F)	mg/l	0.7	1.0
	12.Nitrate (NO_3)	mg/l	45	45
	13.Alkybenzyl Sulfonate (ABS)	mg/l	0.5	1.0
	14.Phenolic substances (as phenol)	mg/l	0.001	0.002
Toxic elements	1.Mercury (Hg)	mg/l	0.001	-
	2.Lead (Pb)	mg/l	0.05	-
	3.Arsenic (As)	mg/l	0.05	-
	4.Selenium (Se)	mg/l	0.01	-
	5.Chromium (Cr hexavalent)	mg/l	0.05	-
	6.Cyanide (CN)	mg/l	0.2	-
	7.Cadmium (Cd)	mg/l	0.01	-
	8.Barium (Ba)	mg/l	1.0	-
Bacterial	1.Standard plate count	Colonies/cm^3	500	-
	2.Total coliform	MPN/100 cm^3	2.2	-
	3.E.coli	MPN/100 cm^3	none	-

Remark: mg/l milligram per liters, MPN Most Probable Number

[a] These values are allowed for tap water or groundwater that is used temporary as drinking. Such water with a parameter between the maximum acceptable concentration and the maximum allowable concentration can not be certified as standard drinking water for industrial products and stamped with the standard logo.

[b] If the calcium concentration is higher than the standard value and the magnesium concentration is lower than the standard value, calcium and magnesium will be identified in term of total hardness which standard value is less than 300 mg/l (as $CaCO_3$).

[c] If the sulphate concentration of 250 mg/l is reached, the magnesium concentration must not be higher than 30 mg/l.

Table 4.7 Groundwater quality standards for drinking purpose (from Notification of the Ministry of Industry, No. 4, B.E. 2521, 1978).

Properties	**Parameters**	**Units**	**Standard**	
			Suitable allowance	**Maximum allowable**
Physical	1.Color	Platinum-Cobalt (Pt-Co)	5	15
	2.Turbidity	Silica scale unit (SSU)	5	20
	3.pH	-	7.0-8.5	6.8-9.2
Chemical	1.Total solid	mg/l	600	1,200
	2.Iron (Fe)	mg/l	0.5	1.0
	3.Manganese (Mn)	mg/l	0.3	0.5
	4.Copper (Cu)	mg/l	1.0	1.5
	5.Zinc (Zn)	mg/l	5.0	15
	6.Sulphate (SO_4)	mg/l	200	250
	7.Chloride (Cl)	mg/l	250	600
	8.Fluoride (F)	mg/l	0.7	1.0
	9.Nitrate (NO_3)	mg/l	45	45
	10.Total Hardness as $CaCO_3$	mg/l	300	500
	11.Non-carbonate hardness as $CaCO_3$	mg/l	200	250
Toxic elements	1.Mercury (Hg)	mg/l	none	0.05
	2.Lead (Pb)	mg/l	none	0.1
	3.Arsenic (As)	mg/l	none	0.05
	4.Selenium (Se)	mg/l	none	0.001
	5.Cyanide (CN)	mg/l	none	0.01
	6.Cadmium (Cd)	mg/l	none	0.01
Bacterial	1.Standard plate count	Colonies/cm^3	500	-
	2.Total coliform	MPN/100 cm^3	2.2	-
	3.E.coli	MPN/100 cm^3	none	-

Remark: mg/l milligram per liters, MPN Most Probable Number

Table 4.8 The permissible limits prescribed by WHO for drinking purposes and the resulting undesirable effect on human system (from Subramani *et al*., 2005).

Parameters	Units	WHO international standard (1971, 1983)		Undesirable effect
		Most desirable limits	Maximum allowable limits	
1.pH	-	7-8.5	9.2	Taste
2.Total solid	mg/l	500	1,500	Gastrointestinal irrigation
3.Toal hardness	mg/l	100	500	Scale formation
4.Sodium (Na)	mg/l	-	200	-
5.Calcium (Ca)	mg/l	75	200	Scale formation
6.Magnesium (Mg)	mg/l	50	150	Scale formation
7.Chloride (Cl)	mg/l	200	600	Salty taste
8.Sulphate (SO_4)	mg/l	200	400	Laxative effect
9.Nitrate (NO_3)	mg/l	45	-	Blue baby
10. Fluoride (F)	mg/l	-	1.5	Fluorosis

Table 4.9 Process for effective removal of drinking water contamination (from Driscoll, 1989).

Parameter	Cause	Treatment
Total hardness	Calcium and magnesium salts	All calcium and magnesium salts removed with cation-exchange water softener.
Iron	Iron dissolved from old pipe with water having a pH below 6.8. Colloidal iron	Calcite filter to remove precipitated iron. Constant chlorination followed by activated-carbon filter to dechlorinate.
Chloride	Excessive salt content High-temperature drying creates chloride concentration, accelerating corrosion.	Use chloride-resistant metals. Reduce total dissolved solids by distillation, ion exchange, or reverse osmosis.
Fluoride	Fluoride above 1-2 mg/l in nature water supply.	Reduce to 0.2 mg/l with activated alumina resins or bone-char filter. Distillation system for drinking or cooking water.

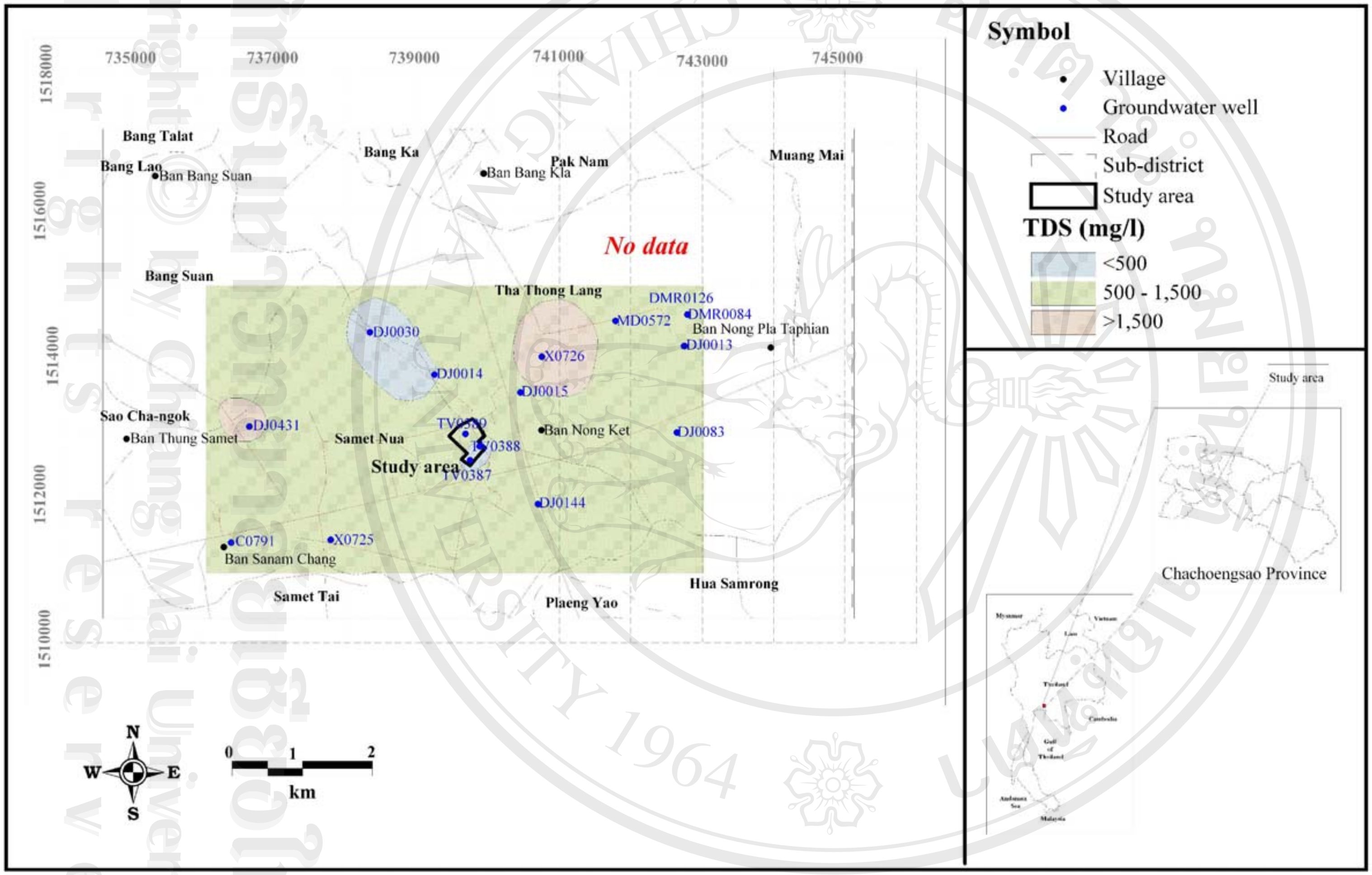

Figure 4.5 Total dissolved solids concentration in the study area and its adjacent.

maximum allowable limit at 200 mg/l. Concentration of sodium ranges from 18 to 690 mg/l. Most groundwater samples exceeds the maximum allowable limits that probably caused by ion exchange. Calcium concentration is high and ranges from 16 to 160 mg/l but generally lower than the maximum allowable limit. Chloride ranges from 10 to 1,700 mg/l and fluoride ranges from 0.1 to 2.9 mg/l indicating that some groundwater samples exceed the maximum allowable limits. Figure 4.6 show the distribution map of chloride where only one sample exceeds the maximum allowable limit of 600 mg/l.

In the study area, most constituents are generally below the maximum allowable limits, except fluoride concentration in some groundwater samples is higher than 1.5 mg/l. From the most desirable and maximum allowable limits for drinking water of WHO and drinking water quality standards of Thailand, groundwater in the study area can be used for drinking purpose without any risk if fluoride is removed.

4.3.2 Agricultural use

The suitability of groundwater for agriculture is considered by the effects of the mineral constituents of the water on both the plant and soil (Todd, 1980). Sodium concentration is important for classifying agriculture water because sodium reacts with soil to reduce its permeability. When sodium-rich water is applied to soil, some of the sodium is taken up by clay; the clay gives up calcium and magnesium in exchange. This reaction, called base exchange, alters the physical characteristics of soil and can even lead to growth retardation. Clay that takes up sodium becomes sticky and slick when wet and has low permeability (Driscoll, 1989).

Sodium content can be considered in terms of percent sodium that known as sodium percentage, or soluble-sodium percentage. It is defined by equation (4.1) as follows:

$$\%Na = \frac{(Na + K)}{Ca + Mg + Na + K} x100 \qquad \text{(Eq. 4.1)}$$

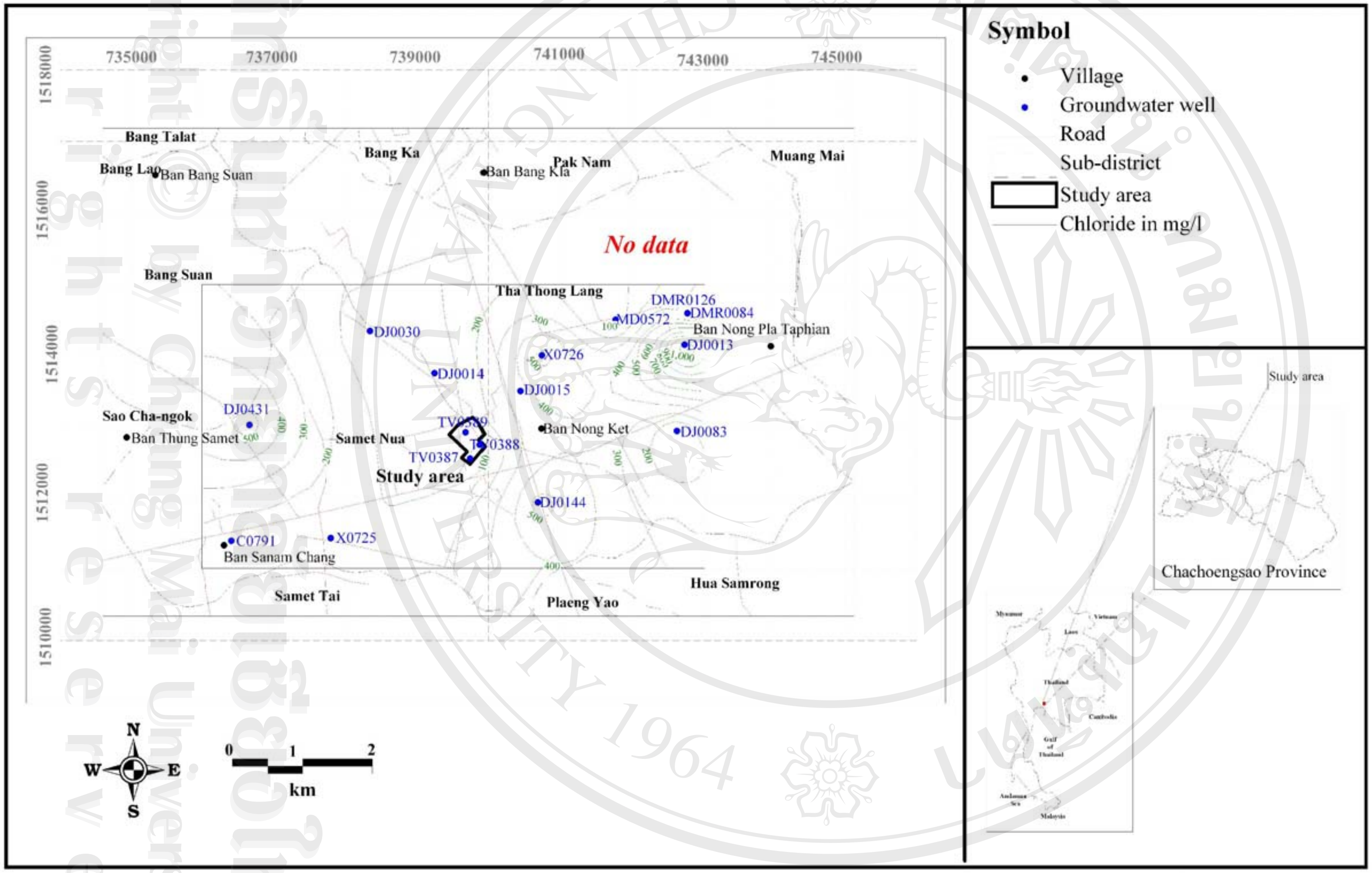

Figure 4.6 Distribution map of chloride in the study area and its adjacent.

Where all ion concentrations are expressed in milliequivalents per liter (meq/l). Recommended water classification for sodium percentage is shown in Table 4.10.

The sodium percentage in the study area and its adjacent range from 12.75 to 91.34, indicate that most groundwater samples are doubtful to unsuitable except few groundwater samples are excellent for agricultural use (Table 4.11). In the study area, sodium percentage range from 79.39 to 91.34, indicate that the groundwater is doubtful to unsuitable for agricultural use.

The importance of sodium leads to adoption of a method to measure the effect of sodium ions. The sodium effect can be calculated by the sodium adsorption ratio (SAR). The sodium adsorption ratio is calculated from the following equation (4.2):

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}} \qquad \text{(Eq. 4.2)}$$

Where all concentration are expressed in milliequivalents per liter (meq/l)

A soil high in exchange sodium is very undesirable for agricultural because it can become deflocculated and tends to have a relatively impermeable crust. This condition is promoted by water of high sodium adsorption ratio and reversed by water containing a high proportion of calcium and magnesium. Soil amendment such as gypsum or lime may correct the situation (Walton, 1970).

Recommended water classifications for sodium adsorption ratio (SAR) is shown in Table 4.12.

The sodium adsorption ratio of groundwater samples in the study area and its adjacent is shown in Table 4.13. Range of the sodium adsorption ratio is from 0.5 to 10.90, indicate that the groundwater samples are good to excellent water. In the study area, the sodium adsorption ratio range from 9.29 to 10.90, indicate that the groundwater samples are good to excellent water. This implies that no alkali hazard is anticipated to the crop. If the sodium adsorption ratio value is greater than 6 to 9, the agricultural water will cause permeability problems on shrinking and swelling types of clayey soils (Saleh *et al*., 1999).

Table 4.10 Water classification for sodium percentage (from Todd, 1980).

Water class	**% Na**
Excellent	<20
Good	20-40
Permissible	40-60
Doubtful	60-80
Unsuitable	>80

Table 4.11 Suitability of groundwater for agricultural use based on sodium percentage in the study area and its adjacent.

Well No.	**%Na**
C0791	85.66
DJ0013	42.50
DJ0014	12.75
DJ0030	16.22
DJ0083	84.86
DJ0144	72.00
DJ0431	65.89
DMR0084	75.00
DMR0126	76.93
X0725	86.04
X0726	68.00
TV0387	91.34
TV0388	89.24
TV0390	79.39

Table 4.12 Water classification for the sodium adsorption ratio (SAR) (from Todd, 1980).

Water class	**SAR**
Excellent	<10
Good	10-18
Fair	18-26
Poor	>26

Table 4.13 The sodium adsorption ratio (SAR) of groundwater sample in the study area and its adjacent.

Well No.	**SAR**
C0791	9.91
DJ0013	4.94
DJ0014	0.56
DJ0030	0.50
DJ0083	9.09
DJ0144	8.05
DJ0431	7.96
DMR0084	8.22
DMR0126	5.89
X0725	9.12
X0726	8.24
TV0387	10.90
TV0388	9.29
TV0390	9.31

Moreover, classification of irrigation water can be assessed by the Wilcox diagram. The Wilcox diagram is based on electrical conductivity and sodium adsorption ratio. The interpretation of the quality class rating is as follows (Driscoll, 1989):

Conductivity (Salinity)

Lower-salinity water (C1): can be used for most crops and soils with little likelihood that soil salinity will developed. Some leaching is required, but this occurs under normal irrigation on all but the tightest of soils.

Medium-salinity water (C2): can be used where a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

High-salinity water (C3): cannot be used on soils that have restricted drainage. With adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

Very high-salinity water (C4): is not suitable for irrigation under ordinary conditions. If used, the soils must be permeable, drainage must be adequate, considerable excess irrigation water must be applied, and very salt-tolerant crops should selected.

Sodium adsorption ratio (SAR)

Low-sodium water (S1): can be used with little danger on nearly all soils. Sodium-sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentration of sodium.

Medium-sodium water (S2): is hazardous for use on fine-textured soils that have high cation exchange capacity. This water may be used on coarse-textured or organic soils with good permeability.

High-sodium water (S3): may be harmful to most soils and thus require special soil management: good drainage, high leaching, and addition of organic matter conditions. Chemical amendments may be necessary except for gypsiferous soils.

Very high-sodium water (S4): is generally unsatisfactory for irrigation purpose, except at low salinity and where calcium from the soil or use of gypsum or other mineral additions may make these waters usable.

Water can be divided into 16groups from specific properties. These groups are C1S1, C1S2, C1S3, C1S4, C2S1, C2S2, C2S3, C2S4, C3S1, C3S2, C3S3, C3S4, C4S1, C4S2, C4S3, and C4S4. Generally, water of low to medium salinity hazard and low to medium hazard, C1S1, C2S1, C1S2, and C2S2, is suitable for irrigation. Water of high salinity hazard but low sodium hazard or low salinity hazard but high sodium hazard, C3S1, and C1S3, should be avoided if possible. All other water groups are not suitable for irrigation.

From Wilcox diagram (Figure 4.7), groundwater samples in the study area and its adjacent can be classified as 6 groups: 2 samples of C2S1, 2 samples of C2S2, 1 sample of C3S1, 6 samples of C3S2, 2 samples of C4S2, and 1 samples of C4S3. Most groundwater samples are not suitable for irrigation. In the study area, groundwater can be classified into 2 groups, as follows: 2 samples of C2S2, indicating that the groundwater samples are suitable for irrigation, and 1 samples of C3S2, indicating that the groundwater sample is not suitable for irrigation.

In summary and according to sodium percentage (% Na) and the Wilcox diagram, groundwater quality in the study area and its adjacent are not suitable for agricultural use.

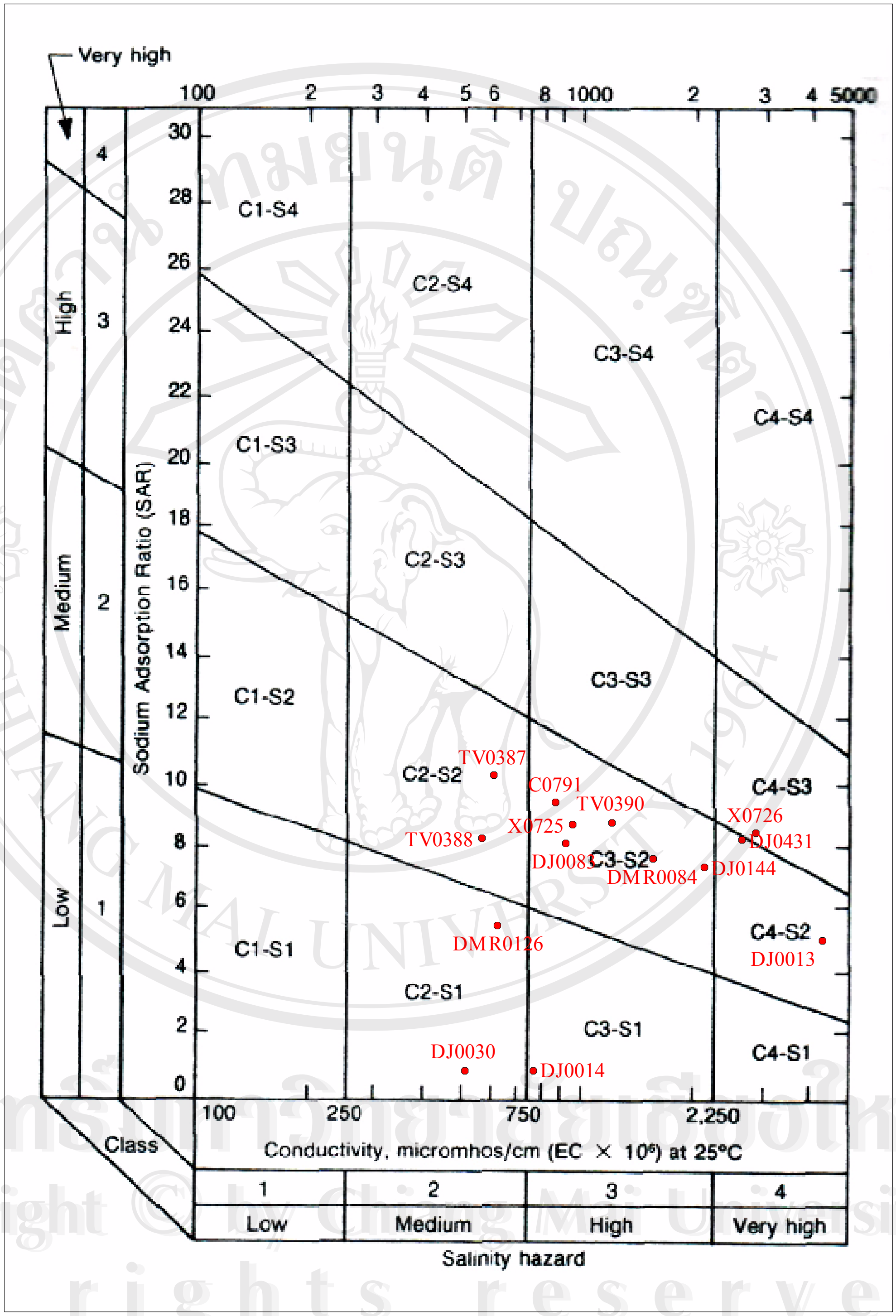

Figure 4.7 Classification of irrigation water based on SAR and conductivity using Wilcox diagram.