CHAPTER 5

TEST BOREHOLE DRILLING SURVEY

CHAPTER 5 TEST BOREHOLE DRILLING SURVEY

5.1 Outline of Survey

5.1.1 Purpose of Survey

Test borehole drilling survey consists of drilling work, geophysical logging in borehole, well construction, pumping test and water quality test. This survey was carried out to obtain the following information related hydrogeology;

- Geological condition / structure
- Aquifer / groundwater condition
- Monitoring groundwater level / water quality

The above mentioned information is utilized for consideration of the groundwater potential.

5.1.2 Survey Area and Quantity

The test borehole drilling survey was carried out in 24 communes as shown in Figure 5.1.1. Information of location, drilling length and diameter is tabulated in Table 5.1.1.

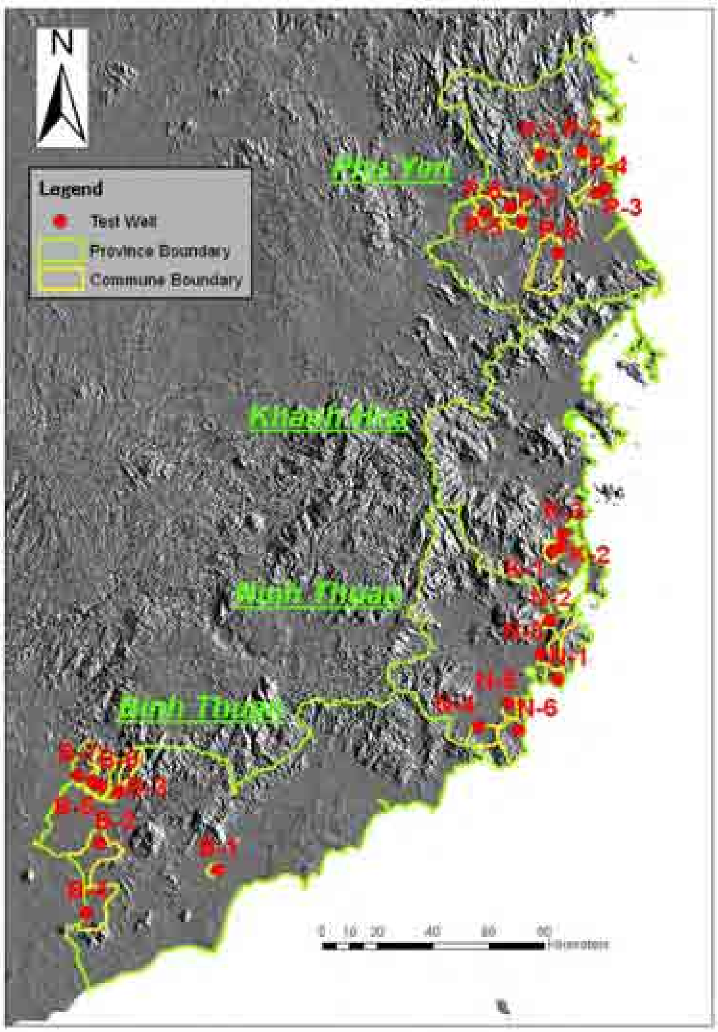


Figure 5.1.1 Location of the Test Boreholes

Table 5.1.1 Coordinates and Drilling Length of the Test Boreholes

Province	Test well No.	Commune	Coordinates		Drilling Length (m)												
			Longitude	Latitude	Total	110mm ≤ D < 150mm			150mm ≤ D < 200mm			200mm ≤ D < 250mm			250mm ≤ D		
						from	*to*	subtotal	*from*	*to*	subtotal	*from*	*to*	subtotal	*from*	*to*	subtotal
Phu Yen	P-1	Xuan Phuoc	109.04726	13.30599	100.0	*55.0*	*100.0*	45.0	*40.0*	*55.0*	15.0	*10.0*	*40.0*	30.0	*0.0*	*10.0*	10.0
	P-2	An Dinh	109.18602	13.31728	100.0	*34.7*	*100.0*	65.3	*32.0*	*34.7*	2.7				*0.0*	*32.0*	32.0
	P-3	An Tho	109.23581	13.18415	100.0	*65.0*	*100.0*	35.0				*4.0*	*65.0*	61.0	*0.0*	*4.0*	4.0
	P-4	An My	109.26448	13.19961	100.0	*75.0*	*100.0*	25.0				*10.0*	*75.0*	65.0	*0.0*	*10.0*	10.0
	P-5	Son Phuoc	108.94888	13.13784	100.0	*35.0*	*100.0*	65.0				*10.0*	*35.0*	25.0	*0.0*	*10.0*	10.0
	P-6	Ea Cha Rang	108.86508	13.11597	100.0	*65.0*	*100.0*	35.0				*10.0*	*65.0*	55.0	*0.0*	*10.0*	10.0
	P-7	Suoi Bac	108.99036	13.08817	100.0	*60.0*	*100.0*	40.0	*53.0*	*60.0*	7.0	*15.0*	*53.0*	38.0	*0.0*	*15.0*	15.0
	P-8	Son Thanh Dong	109.11189	12.98624	100.0	*62.0*	*100.0*	38.0				*10.0*	*62.0*	52.0	*0.0*	*10.0*	10.0
Khanh Hoa	K-1	Cam An Bac	109.09691	12.01491	100.0	*52.0*	*100.0*	48.0				*15.0*	*52.0*	37.0	*0.0*	*15.0*	15.0
	K-2	Cam Hiep Nam	109.12833	12.03166	100.0	*50.0*	*100.0*	50.0				*15.0*	*50.0*	35.0	*0.0*	*15.0*	15.0
	K-3	Cam Hai Tay	109.13242	12.07145	100.0	*45.0*	*100.0*	55.0				*10.0*	*45.0*	35.0	*0.0*	*10.0*	10.0
Ninh Thuan	N-1	Nhon Hai	109.11866	11.59964	100.0	*59.0*	*100.0*	41.0				*24.0*	*59.0*	35.0	*0.0*	*24.0*	24.0
	N-2	Cong Hai	109.09243	11.79183	100.0	*29.0*	*100.0*	71.0				*9.0*	*29.0*	20.0	*0.0*	*9.0*	9.0
	N-3	Bac Son	109.06321	11.68137	100.0	*31.0*	*100.0*	69.0				*11.0*	*31.0*	20.0	*0.0*	*11.0*	11.0
	N-4	Phuoc Minh	108.85868	11.44328	100.0	*40.0*	*100.0*	60.0				*15.0*	*40.0*	25.0	*0.0*	*15.0*	15.0
	N-5	Phuoc Hai	108.95668	11.51905	100.0	*36.0*	*100.0*	64.0				*16.0*	*36.0*	20.0	*0.0*	*16.0*	16.0
	N-6	Phuoc Dinh	108.99058	11.43236	100.0	*68.0*	*100.0*	32.0	*45.0*	*68.0*	23.0				*0.0*	*45.0*	45.0
Binh Thuan	B-1	Muong Man	108.00755	10.96756	100.0	*40.0*	*100.0*	60.0				*10.0*	*40.0*	30.0	*0.0*	*10.0*	10.0
	B-2	Gia Huynh	107.61388	11.04980	100.0	*50.0*	*100.0*	50.0				*16.3*	*50.0*	33.7	*0.0*	*16.3*	16.3
	B-3	Nghi Duc	107.67623	11.22192	100.0	*45.0*	*100.0*	55.0				*8.0*	*45.0*	37.0	*0.0*	*8.0*	8.0
	B-4	Tan Duc	107.57540	10.82483	100.0	*50.0*	*100.0*	50.0				*16.5*	*50.0*	33.5	*0.0*	*16.5*	16.5
	B-5	Me Pu	107.61547	11.23679	100.0	*35.0*	*100.0*	65.0				*10.0*	*35.0*	25.0	*0.0*	*10.0*	10.0
	B-6	Sung Nhon	107.58761	11.25144	100.0	*67.0*	*100.0*	33.0				*11.0*	*67.0*	56.0	*0.0*	*11.0*	11.0
	B-7	Da Kai	107.53850	11.27367	100.0	*35.0*	*100.0*	65.0				*10.0*	*35.0*	25.0	*0.0*	*10.0*	10.0

5.2 Selection of Test Borehole Location

5.2.1 Concept of Selection of the Test Borehole Locations

Concepts of selection of the test borehole locations were as follows.

(1) Utilization of information of the existing wells

The information of existing wells was very few in the target communes; however those are very important for grasping hydrogeological conditions. Therefore the information was collected and be analyzed.

(2) Utilization of the existing GIS data

The GIS data generated on Mapinfo by Vietnam side was utilized in combined with the below mentioned remote sensing in order to effectively analyze hydrogeological conditions.

(3) Utilization of remote sensing

Topographic map of the communes was prepared; and geomorphological and geological structure analysis was conducted using the SRTM (Shuttle Radar Topographic Mission) DEM (Digital Elevation Model) data.

(4) Utilization of results of the geophysical survey

Five (5) candidate sites for the groundwater source per one (1) commune were selected on average based on the results of hydrogeological analysis including the field reconnaissance. Then geophysical survey was conducted at the selected sites.

(5) Evaluation of the candidate locations for the test boreholes and selection

Candidate locations for test boreholes were evaluated on the basis of the results of the above mentioned analyses. Five indices: namely, lineaments, catchment area, aquifer thickness, electric resistivity (permeability), water quality (saline intrusion), were selected. Then the Study Team evaluated the scores for each index and summed up the total scores, and the location with highest score in each target commune was selected as the test borehole drilling location.

5.2.2 Indices for Evaluation of Possible Test Borehole Locations

(1) Lineaments

Lineaments are important index for rock aquifer because a place with lineament structure has a possibility to have groundwater in the fissure zone or fractured zone.

(2) Catchment area

Catchment area is efficient index to evaluate the groundwater potential. The candidate location with large catchment area generally has large groundwater potential.

(3) Aquifer thickness

Aquifer thickness is fundamental data that has direct influence on pumping yield of a well. This index was evaluated with geophysical survey results.

(4) Electric resistivity (permeability)

Permeability of aquifer is fundamental data that has direct influence on pumping yield of a well. This index was also evaluated with electric resistivity. (geophysical survey results).

(5) Water quality (saline intrusion)

Salinity by saline intrusion is the most important index for groundwater development in the study area. Allocation of evaluation score for saline intrusion was decided to double scores of the other indices at the maximum. Salinity originated in geological cause, depending on environment of formation or sedimentation, was not taken into consideration due to the lack of the information.

5.2.3 The Results of Evaluation of Test Borehole Locations

Candidates of test borehole locations were evaluated by using indices above mentioned. The scores were relatively allocated to the candidates because the condition of those indices was different from commune to commune..

The results of evaluation of test borehole locations was shown in the Table 5.2.1 to Table 5.2.4.

Table 5.2.1 The Result of the Evaluation of Proper Test Borehole Locations (Phu Yen Province)

	Point No.		Commune	Geology	Geomorphology						Water Quality			Aquifer Conditions							Total Score
					Lineaments			Catchment Area			Saline Intrusion			Aquifer Thickness			Electric Resistivity				
					Significant	Midium	Low	Large	Middle	Small	Low	Midium	Significant	Thick	Medium	Thin	Low(Clay)	Low	Midium	Hight	
					5	3	1	5	3	1	10	5	1	5	3	1	0	5	3	1	
Phu Yen	P1	P1-V01	Xuan Phuoc	Granitic Rock		X		X			x			X				X			28
		P1-V02		Granitic Rock		X		X			x					X			X		22
		P1-V03		Granitic Rock		X		X			x				X				X		24
		P1-V04		Granitic Rock		X		X			x					X			X		22
		P1-V05		Granitic Rock			X	X			x				X				X		22
	P2	P2-V01	An Dinh	Basalt		X		X			x			X				X			28
		P2-V02		Basalt		X		X			x				X				X		24
		P2-V03		Basalt			X	X			x					X			X		20
		P2-V04		Basalt		X		X			x				X				X		24
		P2-V05		Basalt		X		X			x				X			X			26
	P3	P3-V01	An Tho	Basalt/Plutonic rock			x		x		x			x				x			24
		P3-V02		Basalt/Plutonic rock			x			x	x				x			x			20
		P3-V03		Basalt/Plutonic rock			x			x	x					x		x			18
		P3-V04		Basalt/Plutonic rock			x		x		x					x	x				15
		P3-V05		Basalt/Plutonic rock			x		x		x			x				x			24
	P4	P4-V01	An My	Sediment			x	x				x				x		x			17
		P4-V02		Sediment			x	x					x			x		x			13
		P4-V03		Basalt/Plutonic rock			x	x			x					x		x			22
		P4-V04		Sediment			x	x				x			x			x			19
		P4-V05		Sediment			x	x				x				x		x			17
	P5	P5-V01	Son Phuoc	Basalt/Plutonic rock			x			x	x					x			x		16
		P5-V02		Basalt/Plutonic rock			x			x	x					x			x		16
		P5-V03		Basalt/Plutonic rock			x			x	x					x			x		16
		P5-V04		Basalt/Plutonic rock			x		x		x				x			x			22
		P5-V05		Basalt/Plutonic rock			x		x		x					x			x		18
	P6	P6-V01	Ea Cha Rang	Basalt/Plutonic rock			x			x	x					x			x		16
		P6-V02		Basalt/Plutonic rock			x			x	x					x			x		16
		P6-V03		Basalt/Plutonic rock			x			x	x				x			x			20
		P6-V04		Basalt/Plutonic rock			x		x		x					x				x	16
		P6-V05		Basalt/Plutonic rock			x		x		x					x			x		18
	P7	P7-V01	Suoi Bac	Basalt/Plutonic rock			x		x		x					x			x		18
		P7-V02		Basalt/Plutonic rock			x		x		x					x			x		18
		P7-V03		Basalt/Plutonic rock			x		x		x					x			x		18
		P7-V04		Basalt/Plutonic rock		x			x		x			x				x			26
		P7-V05		Basalt/Plutonic rock			x		x		x				x			x			22
	P8	P8-V01	Son Thanh Dong	Basalt			x		x		x					x			x		18
		P8-V02		Basalt		x			x		x				x			x			24
		P8-V03		Basalt			x		x		x					x			x		18
		P8-V04		Basalt			x		x		x					x			x		18
		P8-V05		Basalt			x		x		x				x			x			22

"Point No." is same as geophysical survey point.

Source: JICA Study Team

Table 5.2.2 The Result of the Evaluation of Proper Test Borehole Locations (Khanh Hoa Province)

Point No.			Commune	Geology	Geomorphology						Water Quality			Aquifer Conditions							Total Score
					Lineaments			Catchment Area			Saline Intrusion			Aquifer Thickness			Electric Resistivity				
					Significant	Midium	Low	Large	Middle	Small	Low	Midium	Significant	Thick	Medium	Thin	Low(Clay)	Low	Midium	Hight	
					5	3	1	5	3	1	10	5	1	5	3	1	0	5	3	1	
Khanh Hoa	K1	K1-V01	Cam An Bac	Sediment/Granite			X	X			x					X				X	18
		K1-V02		Sediment/Granite			X		X		x				X				X		20
		K1-V03		Sediment/Granite		X				X	x					X				X	16
		K1-V04		Sediment/Granite			X		X		x					X				X	16
	K2	K2-V01	Cam Hiep Nam	Sediment/Granite			X		X		x					X				X	16
		K2-V02		Sediment/Granite			X	X			x					X				X	18
		K2-V03		Sediment/Granite		X				X	x				X				X		20
		K2-V04		Sediment/Granite			X		X		x					X				X	16
		K2-V05		Sediment/Granite			X	X			x			X				X	X		29
	K3	K3-V01	Cam Hai Tay	Sediment/Granite			X	X					x			X			X		11
		K3-V02		Sediment/Granite		X		X					x			X			X		13
		K3-V03		Sediment/Granite			X	X					x			X			X		11
		K3-V04		Sediment/Granite			X	X				x		X					X		19
		K3-V05		Sediment/Granite			X	X					x		X				X		13
		K3-V06		Sediment/Granite			X	X					x			X			X		11

"Point No." is same as geophysical survey point.

Source: JICA Study Team

Table 5.2.3 The Result of the Evaluation of Proper Test Borehole Locations (Ninh Thuan Province)

Point No.			Commune	Geology	Geomorphology						Water Quality			Aquifer Conditions							Total Score
					Lineaments			Catchment Area			Saline Intrusion			Aquifer Thickness			Electric Resistivity				
					Significant	Midium	Low	Large	Middle	Small	Low	Midium	Significant	Thick	Medium	Thin	Low(Clay)	Low	Midium	Hight	
					5	3	1	5	3	1	10	5	1	5	3	1	0	5	3	1	
Ninh Thuan	N1	N1-V01	Nhon Hai	Sediment/Granite			X		X			x			X				X		15
		N1-V02		Sediment/Granite			X		X			x		X					X		17
		N1-V03		Sediment/Granite			X		X			x			X				X		15
		N1-V04		Sediment/Granite			X			X		x		X					X		15
	N2	N2-V01	Cong Hai	Sediment/Sedimentary Rock			X		X				x	X						X	11
		N2-V02		Sediment/Sedimentary Rock			X		X			x		X					X		17
		N2-V03		Sediment/Sedimentary Rock			X		X			x				X				X	11
		N2-V04		Sediment/Sedimentary Rock			X		X			x				X				X	11
		N2-V05		Sediment/Sedimentary Rock		X			X			x				X			X		15
	N3	N3-V01	Bac Son	Sediment/Granite		X			X		x				X				X		22
		N3-V02		Sediment/Granite		X			X		x				X				X		22
		N3-V03		Sediment/Granite		X			X		x					X			X		20
		N3-V04		Sediment/Granite			X		X				x		X			X			13
		N3-V05		Sediment/Granite			X	X			x				X				X		22
	N4	N4-V01	Phuoc Minh	Sediment/Granite		X		X			x					X			X		22
		N4-V02		Sediment/Granite			X	X					x			X			X		11
		N4-V03		Sediment/Granite			X	X				x				X			X		15
		N4-V04		Sediment/Granite			X	X				x			X				X		17
	N5	N5-V01	Phuoc Dinh	Sediment/Granite			X	X					x		X				X		13
		N5-V02		Sediment/Granite			X		X			x			X				X		15
		N5-V03		Sediment/Granite			X	X				x				X			X		15
		N5-V04		Sediment/Granite			X		X				x		X			X			13
		N5-V05		Sediment/Granite			X		X			x			X				X		15
	N6	N6-V01	Phuoc Hai	Sediment/Granite			X			X	x				X				X		18
		N6-V02		Sediment/Granite			X			X			x			X			X		7
		N6-V03		Sediment/Granite	X				X		x				X				X		24
		N6-V04		Sediment/Granite			X	X				x				X			X		15
		N6-V05		Sediment/Granite			X			X			x			X			X		7

"Point No." is same as geophysical survey point.

Source: JICA Study Team

Table 5.2.4 The Result of the Evaluation of Proper Test Borehole Locations (Binh Thuan Province)

Point No.			Commune	Geology	Geomorphology						Water Quality			Aquifer Conditions							Total Score
					Lineaments			Catchment Area			Saline Intrusion			Aquifer Thickness			Electric Resistivity				
					Significant	Midium	Low	Large	Middle	Small	Low	Midium	Significant	Thick	Medium	Thin	Low(Clay)	Low	Midium	Hight	
					5	3	1	5	3	1	10	5	1	5	3	1	0	5	3	1	
Binh Thuan	B1	B1-V01	Muong Man	Sediment/Sedimentary Rock			X	X				x				X			X		15
		B1-V02		Sediment/Sedimentary Rock			X	X					x		X				X		13
		B1-V03		Sediment/Sedimentary Rock			X	X				x			X				X		17
		B1-V04		Sediment/Sedimentary Rock			X	X					x		X				X		13
		B1-V05		Sediment/Sedimentary Rock			X	X				x			X				X		17
	B2	B2-V01	Gia Huynh	Sediment/Granite			X	X			x					X			X		20
		B2-V02		Sediment/Granite			X		X		x					X				X	16
		B2-V03		Granite			X			X	x					X				X	14
		B2-V04		Granite			X			X	x					X			X		16
		B2-V05		Sediment/Granite			X	X			x					X				X	18
		B2-V06		Sediment/Granite			X	X			x					X			X		20
	B3	B3-V01	Nghi Duc	Sediment/Granite			X	X			x					X				X	18
		B3-V02		Sediment/Granite			X	X			x					X				X	18
		B3-V03		Sediment/Granite			X	X			x					X				X	18
		B3-V04		Sediment/Granite			X	X			x					X				X	18
		B3-V05		Sediment/Granite			X	X			x					X				X	18
		B3-V06		Sediment/Granite		X		X			x					X			X		22
	B4	B4-V01	Tan Duc	Granite			X		X		x					X			X		18
		B4-V02		Granite			X		X		x					X			X		18
		B4-V03		Granite			X			X	x					X			X		16
		B4-V04		Granite			X		X		x					X			X		18
		B4-V05		Granite		X		X			x					X			X		22
		B4-V06		Granite		X		X			x					X				X	20
	B5	B5-V01	Me Pu	Sediment/Granite			X	X			x					X				X	18
		B5-V02		Sediment/Granite			X	X			x					X			X		20
		B5-V03		Sediment/Granite			X	X			x					X				X	18
		B5-V04		Sediment/Granite			X	X			x					X			X		20
		B5-V05		Sediment/Granite		X		X			x					X			X		22
	B6	B6-V01	Sung Nhon	Sediment/Granite			X	X			x					X				X	18
		B6-V02		Sediment/Granite			X	X			x					X				X	18
		B6-V03		Sediment/Granite			X	X			x					X				X	18
		B6-V04		Sediment/Granite			X	X			x				X					X	20
	B7	B7-V01	Da Kai	Sediment/Granite			X	X			x					X			X		20
		B7-V02		Sediment/Granite			X		X		x					X				X	16
		B7-V03		Sediment/Granite			X		X		x					X			X		18
		B7-V04		Sediment/Granite			X		X		x					X				X	16
		B7-V05		Sediment/Granite			X	X			x					X				X	18

"Point No." is same as geophysical survey point.

Source: JICA Study Team

5.3 Survey Methodology

The test borehole drilling survey was carried out as follows:

(1) Drilling by 110 mm in Diameter

Drilling works by 110 mm in diameter was carried out in order to get geology information, to measure the groundwater level and to make test-hole for the geophysical logging electrical conductivity measurement.

(2) Geophysical Logging in Borehole

The geophysical logging in borehole was carried out in saturated strata. Electrical resistivity and natural gamma were measured by the logging.

(3) Decision of Well Structure

The well structure was decided on the basis of results of the drilling by 110 mm in diameter and geophysical logging.

(4) Expansion of Borehole and Installation of PVC pipe with Screen

Based on the well structure, 110 mm borehole was expanded, and then PVC pipe with screen was installed. After that, back filling, sealing, filter packing and cementation at ground surface were carried out.

(5) Well Development

After the above mentioned process, the borehole was cleaned up by air lifting in order to get natural conditions of groundwater flow.

(6) Protection Work

The protection concrete box with lock was set up.

5.3.1 Drilling

Rotary boring machine was applied in this work with casing pipe and suitable drilling fluid for maintained the borehole wall.

Drilling by 110 mm in diameter was carried out up to 100 m in depth in order to know geology / aquifer conditions and to carry out the geophysical logging in borehole. After determination of a well structure based on results of the drilling and the logging, the borehole diameter was expanded step by step in order to construct wells. The expanded diameter was determined depending on hardness of soil / rock.

Groundwater level was measured at beginning and end of the drilling work.

Boring log was compiled after completion of the site work.

5.3.2 Geophysical Logging in Borehole

Geophysical logging in borehole consists of the electrical resistivity logging and the natural gamma logging in order to clarify location / characteristics of aquifer. The specification of this system is composed of the following items;

(1) Electrical Resistivity

Electrical resistivity logging is one of geophysical explorations to measure the electrical property of each geological unit. This logging can be applicable in water only. Therefore, it is applied to the boreholes with water level. During the logging survey, a current electrode and potential electrode are stabbed into the ground and the other current electrode and potential electrode are installed into the measuring probe which is inserted to the borehole. The electrical resistivity is scanned by the probe while it goes down the borehole.

(2) Natural Gamma

As for natural gamma logging, the measuring module equipped with scintillator measures gamma rays generating from radioactive elements in strata. Since impermeability closely relates to the clay ratio in strata, intensity of the natural gamma ray depends on the content of the potassium (k) in clay.

5.3.3 Well Construction

After determination of the well structure, well construction was carried out.

(1) Standard Well Structure

The standard well structure consists of PVC pipe and screen of 140 mm in diameter as shown in Figure 5.3.1. The screen was applied PVC pipe with hole that aperture ratio was around 5 to 10 %.

(2) Filter Packing, Sealing and Cementation

Well-rounded / sorted gravel was used for filter packing. Its grain size was around 5 mm. Section of the filter packing was made at least 2 m in length and more than the screen length.

Section of the sealing was made at least 1 m in length at the top and bottom of the filter packing section by cohesive materials.

Cementation was conducted around the mouth of the borehole to fix and protect the casing. .

(3) Well Development

After well construction, the well development was conducted by air lifting. The well development was continued until cleanup the groundwater. The groundwater level in borehole was measured 3 hours later after completion of the well development.

(4) Protection Work

The protection box made by concrete with lock was set up to prevent any damage. A signboard was described was attached on the box.

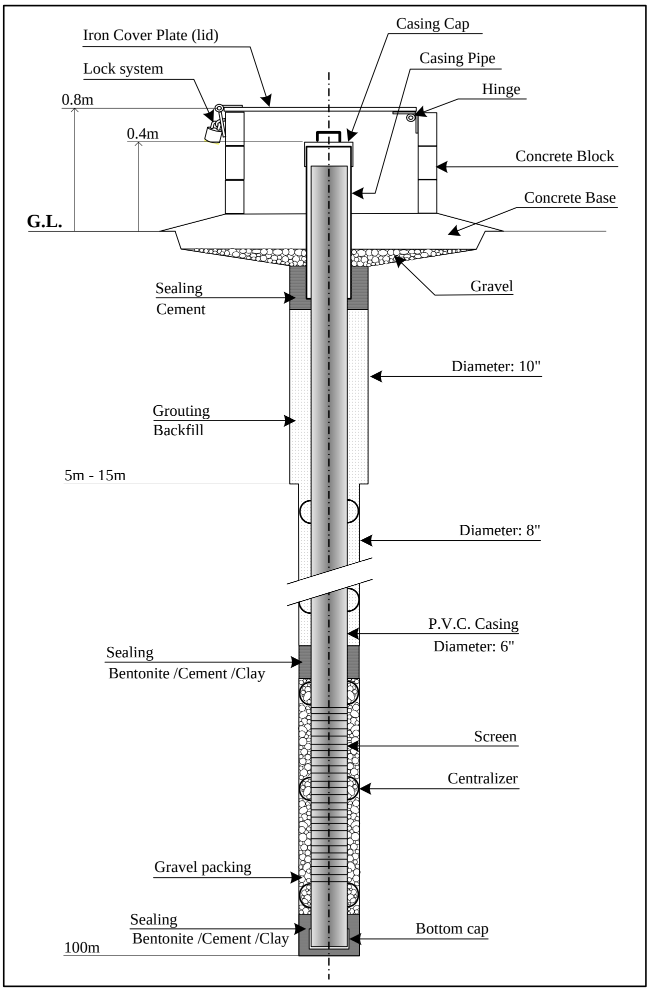


Figure 5.3.1 Schematic Diagram of Well Structure

5.3.4 Pumping Test

The Pumping test consisted of Step Drawdown Test, Constant Rate Pumping Test, and Recovery Test.

(1) Step Drawdown Test

The step drawdown test was carried out by 4 to 6 steps that the number of steps was determined by conditions of available discharge. Observation of each step was basically taken in 120 minutes. In case of that the drawdown did not become stable within 120 minutes, observation was continued by 180 minutes as the maximum time. Table 5.3.1 shows typical schedule of the step drawdown test.

Table 5.3.1 Observation Time Schedule for each Step

Time from start of pumping (minutes)			Time interval of measurement (minutes)
0	-	5	1/2
5	-	10	1
10	-	20	2
20	-	30	3
30	-	60	5
60	-	120	10
120	-	180	10

After completion of the step drawdown test, safety yield was judged, and we took that to decide pumping discharge for the constant rate pumping test.

(2) Constant Rate Pumping Test

The constant rate pumping test was carried out on a discharge determined by results of the step drawdown test. Typical measurement interval is shown in the Table 5.3.2.

Table 5.3.2 Measurement Interval for the Constant Rate Pumping Test

Time from start of pumping (minutes)			Time interval of measurement (minutes)
0	-	5	1/2
5	-	10	1
10	-	20	2
20	-	30	3
30	-	60	5
60	-	120	10
120	-	240	20
240	-	360	40
360	-	720	60
720	-	2,880	120
2,880	-		240

(3) Recovery Test

The recovery test was carried out until the drawdown recovered the static groundwater level that was measured before commencement of the step drawdown test. Duration of the recovery test was at least 12 hours.

5.3.5 Water Quality Test

The water sample for the water quality test was taken after implementation of the pumping test. The water quality test was carried out in conformity with TCVN (TIEU CHUAN VIET NAM). Table 5.3.3 shows analyzed parameters determined by the Counterpart and JICA Study Team.

Table 5.3.3 Parameter of the Water Quality Test

Parameter					
1	Arsenic	9	Chloride Ion	17	Hardness
2	Cyanide	10	Color	18	Total Dissolved Solid
3	Fluoride	11	Taste	19	Turbidity
4	Lead	12	Copper	20	Zinc
5	Nitrate	13	Iron	21	Hydrogen Sulfide
6	Nitrite	14	Manganese	22	Phenol
7	Total Mercury	15	pH	23	Total Coliform
8	Ammonia	16	$KMnO_4$	24	Thermotolerant Coliform

5.4 Results

5.4.1 Summary of Results

Results of the drilling, pumping test and groundwater quality test are tabulated in Table 5.4.1.

Table 5.4.1 Summary of Test Borehole Drilling Survey Results

Province	Test well No.	Commune	Thickness of Alluvium (m)	Type* of Bedrock	Aquifer Type	Pumping Test Results				**Water Quality							
						Static Water Level (GL m)	Draw-down (m)	Safe Yield (l/min)	Safe Yield (m^3/day)	F	Cl^-	Fe	Mn	$KMnO_4$	$CaCo_3$	TDS	Zn
Phu Yen	P-1	Xuan Phuoc	10.0	Gr	Fracture	-2.00	-22.63	4.0	6								
	P-2	An Dinh	3.5	Gr	Alluvium, Fracture	-3.00	-9.30	200.0	288	M	X					X	
	P-3	An Tho	-	Ba, SR	Fracture	-43.50	-6.08	80.0	115					X			
	P-4	An My	8.0	Ba, SR	Fracture	0.80	-14.06	480.0	691								
	P-5	Son Phuoc	1.0	Ba, Gr	Fracture	-6.00	-17.00	4.0	6	X							
	P-6	Ea Cha Rang	4.0	Gr	Fracture	-6.00	-33.81	15.0	22				M				
	P-7	Suoi Bac	2.5	Gr	Fracture	-7.00	-30.10	5.0	7	X							
	P-8	Son Thanh Dong	-	Ba, An	Joint, Fracture	-12.70	-0.91	300.0	432								
Khanh Hoa	K-1	Cam An Bac	11.0	Gr	Weathering, Fracture	-1.60	-9.76	250.0	360			M	M				
	K-2	Cam Hiep Nam	15.0	Gr	Weathering, Fracture	-6.70	-25.17	40.0	58			X					X
	K-3	Cam Hai Tay	10.0	Gr	Intrusive, Fracture	0.60	-15.00	200.0	288								
Ninh Thuan	N-1	Nhon Hai	5.0	Gr	Fracture	-7.00	-29.62	90.0	130		X		M		X	X	
	N-2	Cong Hai	8.7	An	Fracture	-3.50	-11.37	35.0	50								
	N-3	Bac Son	5.0	Gr	Weathering, Fracture	-2.50	-14.10	90.0	130		X	X	X		X	X	
	N-4	Phuoc Minh	2.0	Gr	Fracture	-4.00	-36.00	1.0	1	M	X			M		X	
	N-5	Phuoc Hai	8.0	Gr	Weathering	-1.30	-13.65	60.0	86		X		X	X	X	X	
	N-6	Phuoc Dinh	15.0	Gr	Weathering	-6.80	-13.67	35.0	50	X				X			
Binh Thuan	B-1	Muong Man	10.0	SR	Fracture	-5.30	-7.47	25.0	36								
	B-2	Gia Huynh	5.7	Gr	Fracture	-1.64	-26.41	30.0	43								
	B-3	Nghi Duc	8.0	Gr	Fracture	-1.10	-10.03	3.0	4								
	B-4	Tan Duc	10.0	Gr	Weathering, Fracture	-2.50	-5.87	12.0	17						X		
	B-5	Me Pu	8.0	Gr	Weathering	-1.90	-21.30	45.0	65								
	B-6	Sung Nhon	8.0	Gr	Fracture	-0.80	-19.00	45.0	65								
	B-7	Da Kai	3.0	Ba, Gr	Alteration, Fracture	-5.60	-52.90	4.8	7								

* Gr: Granite, Ba: Basalt, SR: Sedimentary Rock, An: Andesite
** X:Dissatisfy Drinking Water Standards, M: Marginal of Drinking Water Standards

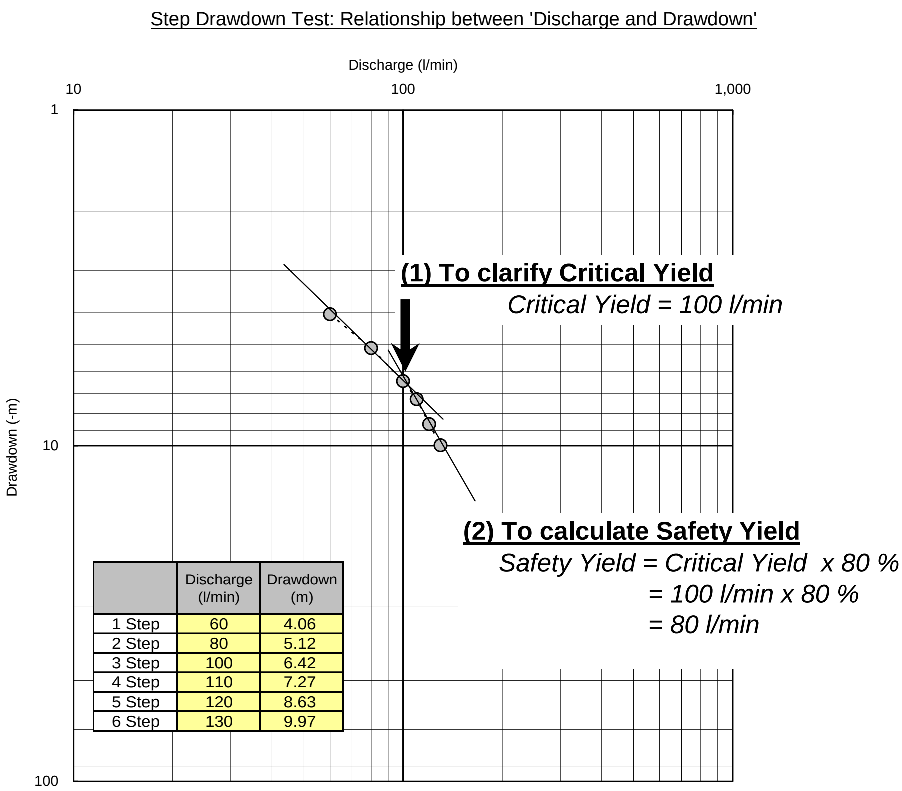
5.4.2 Drilling, Geophysical Logging in Borehole and Well Construction

The suitable well structure was determined on the basis of boring core check, which was observed crack conditions, existence of oxidized brown color, core recovery ratio, etc, and consideration of the geophysical logging results, which was examined low resistivity zone, caliper changes, gamma changes, etc..

5.4.3 Pumping Test

(1) Safety Yield

Pumping test that consists of step drawdown test, constant rate pumping test and recovery test was carried out in order to know safety yield of the test boreholes. Safety yield defines that groundwater is sustainable for water supply, and its value was basically adopted 80 % of critical yield that drawdown from a step shows steep incline obtained by results of the step drawdown test as shown in Figure 5.4.1.



	Discharge (l/min)	Drawdown (m)
1 Step	60	4.06
2 Step	80	5.12
3 Step	100	6.42
4 Step	110	7.27
5 Step	120	8.63
6 Step	130	9.97

Figure 5.4.1 Procedure of Determination of the Safety Yield

Summary of safety yield by each test borehole shows Figure 5.4.2. Test boreholes over 100 l/min in the safety yield evaluated as a rich were at P-1, P-4, P-8, K-1 and K-3, while test boreholes not to exceed 30 l/min in the safety yield evaluated as a poor that is not enough for the hand-pump type water supply were at P-1, P-5, P-6, P-7, N-4, B-1, B-3, B-4 and B-7 as shown in Table 5.4.2.

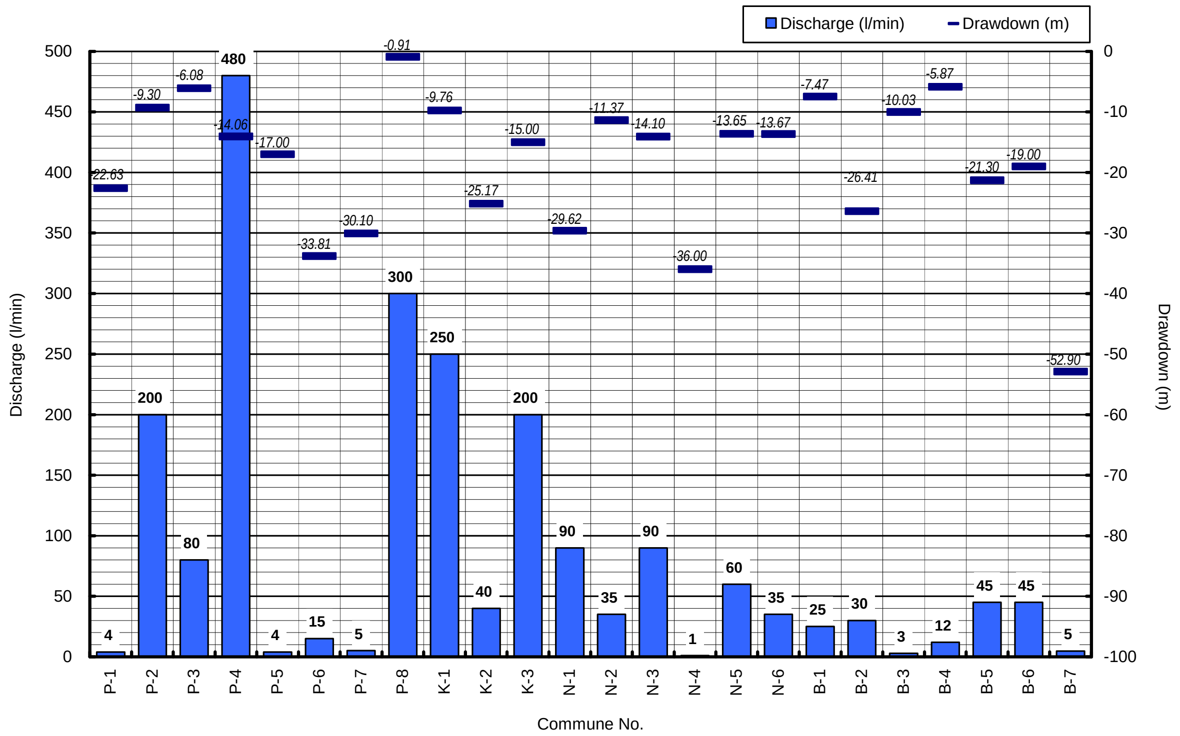


Figure 5.4.2 Safety Yield and its Drawdown by each Test Borehole

Table 5.4.2 Categorization of the Safety Yield by each Test Borehole

Target Communes			Evaluation of Groundwater Amount		
			Rich: More than 100 l/min	Fare: 30 to 100 l/min	Poor: Less than 30 l/min
Phu Yen	P-1	Xuan Phuoc			4
	P-2	An Dinh	200		
	P-3	An Tho		80	
	P-4	An My	480		
	P-5	Son Phuoc			4
	P-6	Ea Cha Rang			15
	P-7	Suoi Bac			5
	P-8	Son Thanh Don	300		
Khanh Hoa	K-1	Cam An Bac	250		
	K-2	Cam Hiep Nam		40	
	K-3	Cam Hai Tay	200		
Ninh Thuan	N-1	Nhon Hai		90	
	N-2	Cong Hai		35	
	N-3	Bac Son		90	
	N-4	Phuoc Minh			1
	N-5	Phuoc Hai		60	
	N-6	Phuoc Dinh		35	
Binh Thuan	B-1	Muong Man			25
	B-2	Gia Huynh		30	
	B-3	Nghi Duc			3
	B-4	Tan Duc			12
	B-5	Me Pu		45	
	B-6	Dung Nhon		45	
	B-7	Da Kai			5

(2) Aquifer Constant

Aquifer constant, such as transmissivity, storage coefficient and permeability coefficient, is roughly revealed from the results of pumping test.

Generally, a pumping well and some observation wells are required to reveal the aquifer constant, however the test boreholes (pumping well) only was made (nothing observation boreholes), because the purpose of the investigation was to directly reveal the safety yield. Moreover, the well equation is based on existence of aquifer that distribution is horizontal continuity, such as Alluvial sandy / gravelly soil. However, the target aquifer in this Study is fissure water born from fracture / intrusive / weathering / joint section of the rock that distribution is discontinuity.

Hence, the aquifer constant was not accuracy to use the value itself for an absolute comparison or some analysis, for instance distance between a pump well and an observation well was assumed as radius of the PVC pipe for the calculation of the aquifer constant. In this report, we treated the aquifer constant as the relative comparison.

The aquifer constant is derived from the following conditions as shown in Table 5.4.3.

Table 5.4.3 Conditions and Equation for Calculation of the Aquifer Constant

Aquifer Constant	Adopted Pumping Tests for the Calculation	Equation
Transmissivity: T	Constant Rate Test Recovery Test	[Jacob Method] $T = \frac{2.3Q_p}{4\pi\Delta s}$ where, Q_p: Discharge (m3/min) s: Drawdown in 1 log-cycle (m)
Storage Coefficient: S	Constant Rate Test	[Jacob Method] $S = 2.25\ T\ (t_0 / r^2)$ where, t_0: time (drawdown =0) (min) r: Distance between a pumping well and a observation well (m)
Permeability Coefficient : k	(Transmissivity)	$k = \frac{100}{60}\left(\frac{T}{D}\right)$ where, D: Thickness of the aquifer (m)

Table 5.4.4 and Figure 5.4.3 show summary of the aquifer constant. It is noted that the transmissivity derived from the constant rate test and the recovery test is quite similar, hence the follower is adopted in Table 5.4.4 and Figure 5.4.3.

Table 5.4.4 Summary of Aquifer Constant

Location	Type of Rock	Aquifer Type	Safety Yield (l/min)	Transmissivity (m^2/min)	Storage Coefficient	Permeability Coefficient (cm/sec)
P-1	Granite	Fracture	4.0	8.9×10^{-5}	8.0×10^{-2}	4.9×10^{-6}
P-2	Granite	Alluvium, Fracture	200.0	3.4×10^{-3}	1.7	8.1×10^{-4}
P-3	Basalt, SR*	Fracture	80.0	1.4×10^{-2}	1.5×10^{-2}	1.6×10^{-3}
P-4	Basalt, SR	Fracture	480.0	3.9×10^{-2}	2.1×10^{-2}	2.6×10^{-3}
P-5	Basalt, Granite	Fracture	4.0	7.8×10^{-5}	5.0×10^{-1}	6.5×10^{-6}
P-6	Granite	Fracture	15.0	3.1×10^{-4}	1.7×10^{-1}	2.5×10^{-5}
P-7	Granite	Fracture	5.0	4.6×10^{-5}	4.1×10^{-1}	4.5×10^{-6}
P-8	Basalt	Joint, Fracture	300.0	3.3×10^{-1}	3.2×10^{1}	2.2×10^{-2}
K-1	Granite	Weathering, Fracture	250.0	2.0×10^{-2}	2.6×10^{-1}	1.1×10^{-3}
K-2	Granite	Weathering, Fracture	40.0	6.0×10^{-4}	1.3	4.0×10^{-5}
K-3	Granite	Intrusive, Fracture	200.0	2.5×10^{-3}	5.8×10^{1}	1.7×10^{-4}
N-1	Granite	Fracture	90.0	1.0×10^{-3}	4.0	5.6×10^{-5}
N-2	Granite	Fracture	35.0	1.0×10^{-3}	1.2×10^{-1}	1.2×10^{-4}
N-3	Granite	Weathering, Fracture	90.0	1.5×10^{-3}	5.1×10^{-1}	1.6×10^{-4}
N-4	Granite	Fracture	1.0	7.4×10^{-6}	2.9×10^{-1}	6.2×10^{-7}
N-5	Granite	Weathering	60.0	2.4×10^{-3}	7.0×10^{-2}	2.7×10^{-4}
N-6	Granite	Weathering	35.0	1.3×10^{-3}	3.2×10^{-1}	8.4×10^{-5}
B-1	SR	Fracture	25.0	2.7×10^{-3}	7.8×10^{-2}	1.8×10^{-4}
B-2	Granite	Fracture	30.0	3.4×10^{-4}	8.5×10^{-2}	2.8×10^{-5}
B-3	Granite	Fracture	3.0	1.4×10^{-4}	4.9×10^{-2}	1.6×10^{-5}
B-4	Granite	Weathering, Fracture	12.0	2.4×10^{-3}	9.7×10^{-4}	1.4×10^{-4}
B-5	Granite	Weathering	45.0	1.5×10^{-3}	1.0×10^{-1}	1.3×10^{-4}
B-6	Granite	Fracture	45.0	7.5×10^{-4}	1.3×10^{1}	4.2×10^{-5}
B-7	Basalt, Granite	Alteration, Fracture	4.8	4.6×10^{-5}	2.5	3.9×10^{-6}

*SR: Sedimentary Rock

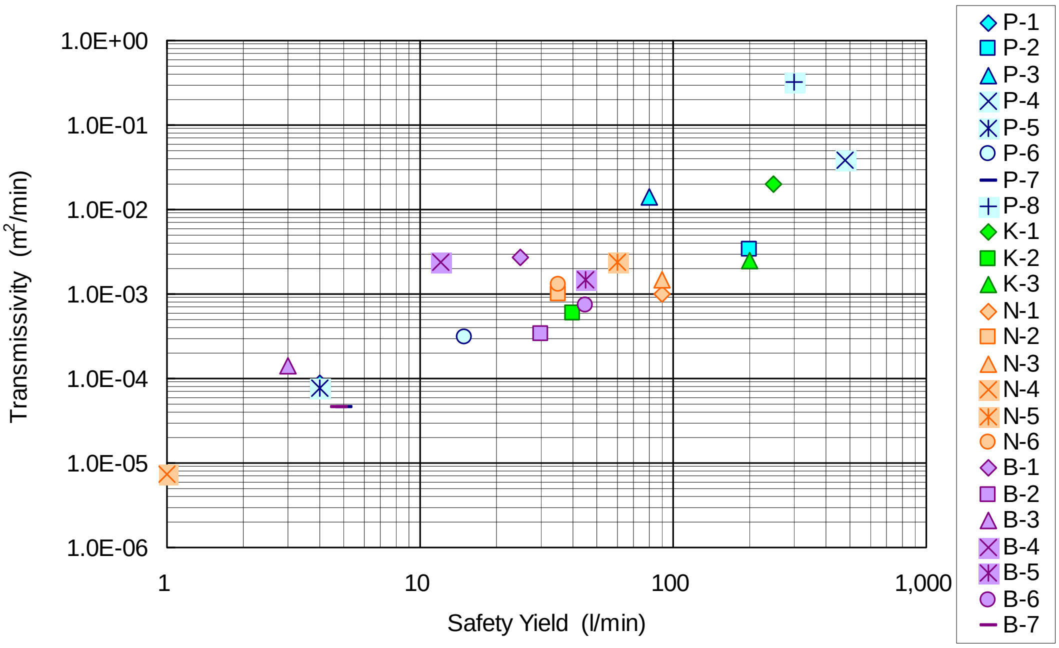


Figure 5.4.3 Relationship between Safety Yield and Transmissivity by 24 Test Boreholes

5.4.4 Water Quality Test

Water quality tests for the groundwater of the test boreholes were carried out in order to judge whether the groundwater is suitable for the water supply or not.

Table 5.4.6 shows tabulation of results of the tests. Values described by white color in the Table 4-8 show an excess of the standard value in conformity with TCVN. It is noted that coliforms results almost show beyond the standard values with unidentified reasons. To verify the results of the water quality test conducted by the local contractor, we ask to re-carry out the groundwater sampling and the tests at K-3, N-2 and N-5 to Pasteur Institute. We cleaned-up the equipments related the water pumping-up using a sterilization agent, and then Pasteur Institute took the samples and executed the test. However, coliforms were still detected beyond the standard values as shown in Table 5.4.5.

Table 5.4.5 Verification of the Water Quality Test (Coliforms)

	Total Coliforms (CFU/100 ml)		Thermotolerant Coliforms (CFU/100 ml)	
	By Local Contractor	By Pasteur Institute	By Local Contractor	By Pasteur Institute
K-3	8×10^3	1,000	2.3×10^3	50
N-2	8×10^5	5,000	1.15×10^4	2,080
N-5	35×10^4	1.3×10^3	17	336

A As for the province-wise considerations in so far as the target communes goes, relatively good quality and not good quality of the groundwater shows in Binh Thuan and in Ninh Thuan, respectively. Regarding the evaluation by each test borehole, usable groundwater for the water supply with viewpoint from water quality was confirmed at P-1, P-4, P-8, K-3, N-2, B-1, B-2, B-5, B-6 and B-7.

Table 5.4.6 Results of the Water Quality Test at 24 Test Boreholes

Item / BH NO.	As	CN	F	Pb	NO_3	NO_2	Hg	NH_4^+	Cl^-	Color (mg/L Pt-Co)	Odor, taste	Cu	Fe	Mn	pH	$KMnO_4$	$CaCO_3$	TDS	Turbidity (NTU)	Zn	Hydrogen sulphide	Phenol	Total coliforms (CFU/100 ml)	Thermotolerant coliforms (CFU/100 ml)
P-1	<0.001	<0.001	0.37	<0.001	0.16	<0.01	<0.001	<0.01	17.73	5	Non	0.002	0.408	0.193	7.49	2.00	60.01	136	4.05	0.018	<0.01	<0.001	$12*10^3$	$1.3*10^3$
P-2	<0.001	<0.001	1.67	<0.001	0.48	<0.01	<0.001	<0.01	960.78	10	Saltish	0.001	0.152	0.158	8.05	1.60	150.02	2,328	2.02	0.020	0.02	<0.001	0	0
P-3	0.001	<0.001	0.04	<0.001	<0.01	0.01	<0.001	<0.01	138.27	0	Non	0.001	0.207	0.012	7.51	5.20	265.04	642	0.5	0.170	<0.01	<0.001	$3*10^3$	100
P-4	0.002	<0.001	0.11	<0.001	0.01	<0.01	<0.001	<0.01	42.54	0	Non	0.001	0.125	0.073	7.68	2.00	215.03	264	1.22	0.098	<0.01	<0.001	460	93
P-5	<0.001	0.006	2.48	0.001	0.01	0.03	<0.001	<0.01	21.27	0	Non	0.001	0.066	0.158	7.98	1.60	80.01	392	2.35	1.002	<0.01	<0.001	$15*10^3$	500
P-6	<0.001	<0.001	0.20	0.001	0.47	0.01	<0.001	<0.01	118.77	5	Non	<0.001	0.193	0.504	7.44	1.80	295.05	556	1.24	0.058	0.01	<0.001	$24*10^3$	$24*10^3$
P-7	<0.001	<0.001	12.44	0.001	0.02	0.03	<0.001	<0.01	85.09	0	Non	0.002	0.185	0.085	8.03	1.60	155.02	490	11.30	0.697	0.02	<0.001	15	4
P-8	<0.001	0.001	0.62	0.002	2.57	<0.01	<0.001	<0.01	10.64	0	Non	0.003	0.012	0.083	7.15	1.60	88.01	156	1.16	0.141	<0.01	<0.001	$16.8*10^3$	$4.25*10^3$
K-1	0.001	<0.001	0.48	0.001	0.01	<0.01	<0.001	<0.01	49.63	0	Non	0.002	0.714	0.585	7.29	1.60	232.54	394	2.36	0.062	<0.01	<0.001	23	17
K-2	<0.001	0.002	0.16	0.002	0.02	0.03	<0.001	<0.01	96	20	Non	0.002	1.08	0.27	6.5	1.20	45	232	8	6.1	0.03	<0.001	$18*10^3$	$18*10^3$
K-3	<0.001	<0.001	1.05	0.001	<0.01	<0.01	<0.001	<0.01	87	0	Non	0.002	0.22	0.49	7.3	1.20	197	411	0	0.1	<0.01	<0.001	$1*10^3$	50
N-1	<0.001	<0.001	1.05	0.001	1.62	0.19	<0.001	<0.01	511	0	Non	0.002	0.01	0.52	7.3	1.30	370	1,258	1	0.3	0.03	<0.001	200	100
N-2	0.006	<0.001	0.99	0.003	0.02	<0.01	<0.001	<0.01	181	0	Non	<0.001	0.11	0.09	7.4	0.60	105	642	1	0.0	<0.01	<0.001	5*103	2.08*103
N-3	0.003	0.003	0.07	0.001	0.85	0.02	<0.001	<0.01	2,340	0	Salty	0.002	1.95	1.05	6.8	2.00	2080	3,802	0	0.0	<0.01	<0.001	$4*10^5$	$52*10^3$
N-4	0.002	0.004	1.59	<0.001	0.66	0.02	<0.001	<0.01	704	10	Saltish	0.001	0.02	0.03	8.0	2.40	270	1,766	1	0.0	<0.01	<0.001	$29*10^5$	$64*10^3$
N-5	<0.001	0.002	0.03	0.001	0.35	0.01	<0.001	<0.01	19,880	10	Salty	<0.001	0.24	4.74	7.1	45.6	8800	40,100	0	0.0	<0.01	<0.001	$1.4*10^4$	336
N-6	<0.001	<0.001	2.23	0.002	7.74	0.02	<0.001	<0.01	340	0	Non	0.001	0.25	0.11	7.6	7.50	155	862	1	0.0	0.02	<0.001	$9*10^6$	$2*10^4$
B-1	0.001	0.001	0.40	0.001	0.03	<0.01	<0.001	<0.01	131	0	Non	0.001	0.26	0.38	7.1	1.20	295	626	1	0.0	<0.01	<0.001	$1*10^5$	$3.33*10^2$
B-2	<0.001	0.002	0.05	<0.001	0.02	<0.01	<0.001	<0.01	14	0	Non	0.001	0.23	0.34	7.3	0.40	140	224	4	0.0	0.02	<0.001	$75*10^3$	$2.5*10^3$
B-3	<0.001	0.001	0.48	0.001	0.03	<0.01	<0.001	<0.01	14	5	Non	0.010	0.16	0.32	7.6	0.80	155	260	10	0.0	0.03	<0.001	250	30
B-4	<0.001	0.004	0.46	0.010	0.02	<0.01	<0.001	<0.01	99	0	Non	0.001	0.08	0.39	7.3	2	365	528	2	0.0	0.02	<0.001	$31.5*10^3$	$15*10^3$
B-5	<0.001	0.003	<0.01	0.002	<0.01	<0.01	<0.001	<0.01	9	0	Non	0.001	0.16	0.20	7.2	1.20	110	212	2	0.0	<0.01	<0.001	$11*10^4$	$24*10^2$
B-6	<0.001	0.001	<0.01	0.002	0.02	<0.01	<0.001	<0.01	32	8	Non	<0.001	0.27	0.18	7.1	0.8	45	134	2	0.0	<0.01	<0.001	200	60
B-7	<0.001	0.005	<0.01	0.004	0.72	<0.01	<0.001	<0.01	11	0	Non	<0.001	0.10	0.29	6.7	1.2	80	156	7	0.0	0.02	<0.001	$138*10^4$	460
Vietnanese Standard No.1329	0.01	0.07	0.7~1.5	0.01	50	3	0.001	1.5	250	15	Non	2	0.5	0.5	6.5~8.5	2	300	1,000	5	3	0.05	0.01	<2.2	0
WHO Guidelines	0.01	0.07	1.5	0.01	50	3	0.001	1.5	250	15	Non	2	0.3	0.4	6.5~9.5	-	500	1000	5	3	0.05	-	0	0

5.5 Availability of Groundwater Development

(1) Suitable Test Boreholes for Groundwater Resource

Suitable test boreholes for the groundwater resource are evaluated on the basis of water volume and quality. As a simplified evaluation, the following requirements are established to select the suitable test boreholes.

- Safety yield is more than 100 l/min.
- Every contents of the water quality test are not excess of the standard values, except for coliforms.

The water volume is the first priority to consider the groundwater development, hence this requirement is used for the first screening. As a result, P-2, P-4, P-8, K-1 and K-3 were selected. Next, the water quality conditions are checked as the second screening, and then P-4, P-8, K-1 and K-3 were selected as a suitable water resource for the water supply as shown in Table 5.5.1 . Although Fe and Mn of K-1 dissatisfy the water quality standards, they can be removed by simple optional facility of water supply system.

Table 5.5.1 Suitable Test Boreholes for Groundwater Resources

Target Communes			Water Volume		Water Quality: Item beyond the standard	Evaluation
			More than 100 l/min	Less than 100 l/min		
Phu Yen	P-1	Xuan Phuoc		44	Coli	
	P-2	An Dinh	200		F, Cl-, Taste, TDS	
	P-3	An Tho		80	KMnO4, Coli	
	P-4	An My	480		Coli	Suitable
	P-5	Son Phuoc		4	F, Coli	
	P-6	Ea Cha Rang		15	Mn. Coli	
	P-7	Suoi Bac		5	F, NTU, Coli	
	P-8	Son Thanh Don	300		Coli,	Suitable
Khanh Hoa	K-1	Cam An Bac	250		Fe, Mn, Coli	
	K-2	Cam Hiep Nam		40	Color, Fe, NTU, Zn, Coli	
	K-3	Cam Hai Tay	200		Coli	Suitable
Ninh Thuan	N-1	Nhon Hai		90	Cl-, Mn, CaCo3, TDS	
	N-2	Cong Hai		35	Coli	
	N-3	Bac Son		90	Cl-, Taste, Fe, Mn, CaCo3, TDS, Coli	
	N-4	Phuoc Minh		1	F, Cl-, Taste, KMnO4, TDS, Coli	
	N-5	Phuoc Hai		60	Cl-, Taste, Mn, KMnO4, CaCO3, TDS, Coli	
	N-6	Phuoc Dinh		35	F, KMnO4, Coli	
Binh Thuan	B-1	Muong Man		25	Coli	
	B-2	Gia Huynh		30	Coli	
	B-3	Nghi Duc		3	NTU, Coli	
	B-4	Tan Duc		12	CaCo3, Coli	
	B-5	Me Pu		45	Coli	
	B-6	Dung Nhon		45	Coli	
	B-7	Da Kai		5	Coli	

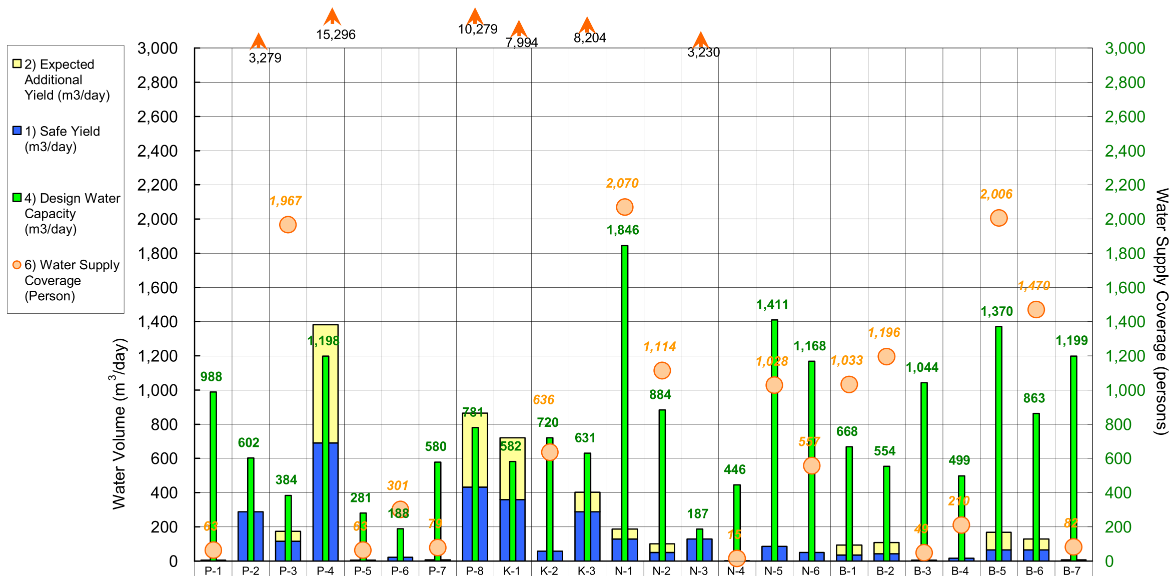
(2) Consideration of Available Pump-up Volume

In consideration of additional withdrawal volume, seawater intrusion and water quality, the following pump-up volume may be available based on the results of hydrogeological exploration, geophysical survey and test borehole drilling survey as shown in Table 5.5.2 and Figure 5.1.1. Some coefficient as a reduction factor of the pump-up volume in comparison with the safety yield of test borehole was adopted in this estimation. In case that a location has similar geological / aquifer conditions with the test borehole, the coefficient for aquifer type of Alluvium / weathering / joint and fracture were set up 1.0 to 0.4 based on the empirical engineering point of view, respectively. Because a distribution of layer type of alluvium is horizontal and continuous but in the case of fissure type, weathering and joint or fracture are existing complicatedly and discontinuously.

Table 5.5.2 Expectation of Available Pump-up Volume in 24 Communes

Location	Type of Rock	Aquifer Type	Safe Yield of Test Borehole (l/min)	Expected Additional Yield	Remarks
P-1	Granite	Fracture	4	0	N/A (Too little yield)
P-2	Granite	Alluvium, Fracture	200	0	Unsuitable water quality
P-3	Basalt, Sedimentary Rock	Fracture	80	80 l/min * 0.5 = 40 l/min	It is difficult to find out the distribution of intrusive basalt. V05 has an advantage of topographic features.
P-4	Basalt, Sedimentary Rock	Fracture	480	480 l/min x (0.5 x 2) = 480 l/min	Up-stream side from the test borehole and valley line is suitable location for the new drilling. 2 more drillings may be available by 500 m interval.
P-5	Basalt, Granite	Fracture	4	0	N/A (Too little yield)
P-6	Granite	Fracture	15	0	N/A (Too little yield)
P-7	Granite	Fracture	5	0	N/A (Too little yield)
P-8	Basalt	Joint, Fracture	300	300 l/min x 1 = 300 l/min	Another borehole with the same yield as the test borehole is expected.
K-1	Granite	Weathering, Fracture	250	250 l/min x 1 = 250 l/min	The test borehole encountered fracture zone generated by some fault. Another borehole with the same yield as the test borehole is expected.
K-2	Granite	Weathering, Fracture	40	0	The test borehole is only expected to get groundwater in consideration with seawater intrusion conditions.
K-3	Granite	Intrusive, Fracture	200	200 l/min x 40% = 80 l/min	The test borehole encountered fracture zone generated by intrusive andesite. Hence, it is difficult to find out the similar conditions. While, another borehole with 40% yield of the test borehole is expected.
N-1	Granite	Fracture	90	90 l/mi x 0.5 = 45 l/min	Another borehole with 50% yield of the test borehole is expected.
N-2	Granite	Fracture	35	35 l/mi x 1 = 35 l/min	Another borehole with the same yield of the test borehole is expected.
N-3	Granite	Weathering, Fracture	90	0	N/A (Seawater Intrusion)
N-4	Granite	Fracture	1	0	N/A (Too little yield and seawater intrusion)

Location	Type of Rock	Aquifer Type	Safe Yield of Test Borehole (l/min)	Expected Additional Yield	Remarks
N-5	Granite	Weathering	60	0	N/A (Seawater Intrusion)
N-6	Granite	Weathering	35	0	N/A (Fluoride)
B-1	Sedimentary Rock	Fracture	25	25 l/min x 0.8 x 2 = 40 l/min	Other two boreholes with 80% yield of the test borehole are expected.
B-2	Granite	Fracture	30	30 l/min x 0.5 x 3 = 45 l/min	Three boreholes with 50% yield of the test borehole are expected.
B-3	Granite	Fracture	3	0	N/A (Too little yield)
B-4	Granite	Weathering, Fracture	12	0	N/A (Too little yield)
B-5	Granite	Weathering	45	45 l/min x 0.8) x 2 = 72 l/min	Other two boreholes with 80% yield of the test borehole are expected.
B-6	Granite	Fracture	45	45 l/min x 0.5 x 2 = 45 l/min	Other two boreholes with 50% yield of the test borehole are expected.
B-7	Basalt, Granite	Alteration, Fracture	5	0	N/A (Too little yield)



	P-1	P-2	P-3	P-4	P-5	P-6	P-7	P-8	K-1	K-2	K-3	N-1	N-2	N-3	N-4	N-5	N-6	B-1	B-2	B-3	B-4	B-5	B-6	B-7
2) Expected Additional Yield (m3/day)	0	0	58	691	0	0	0	432	360	0	115	58	50	0	0	0	0	58	65	0	0	104	65	0
1) Safe Yield (m3/day)	6	288	115	691	6	22	7	432	360	58	288	130	50	130	1	86	50	36	43	4	17	65	65	7
4) Design Water Capacity (m3/day)	988	602	384	1,198	281	188	580	781	582	720	631	1,846	884	187	446	1,411	1,168	668	554	1,044	499	1,370	863	1,199
6) Water Supply Coverage (Person)	63	3,279	1,967	15,296	63	301	79	10,279	7,994	636	8,204	2,070	1,114	3,230	15	1,028	557	1,033	1,196	49	210	2,006	1,470	82

Note :

- Safety Yield: It is obtained from the pumping test. Unit is "m^3/day" and left-hand vertical axis is used.
- Expected Additional Yield: It is calculated / estimated using the safety yield and geological / aquifer conditions as shown in Table 5.5.2. Unit is converted to "m^3/day" and left-hand vertical axis is used.
- Water Supply Coverage: It is assumed that one person uses 60 litters per one day. The value (persons) is calculated that total volume (1) + 2)) divided by "60 l/day". Unit is "persons" and right-hand vertical axis is used.

Figure 5.5.1 Expectation of Available Pump-up Volume and Water Supply in 24 Communes

CHAPTER 6

WATER QUALITY SURVEY

CHAPTER 6 WATER QUALITY SURVEY

Two kinds of water quality survey were conducted in this study. One is “water quality survey of existing water sources and test boreholes” to know the current water quality of groundwater and surface water, and groundwater recharge conditions. The other is “seawater intrusion survey” to know affection of saline wedge intrusion into groundwater in the target communes.

6.1 Water Quality Survey of Existing Water Sources and Test Wells

6.1.1 Purpose of the Survey

Water sampling and water quality test for the selected existing wells, surface water and test wells in the 24 communes were carried out. The purpose of the survey is to know the currant water quality, recharge conditions for the evaluation of groundwater development potentiality in the targeted communes.

6.1.2 Methodology of Survey

(1) Items of Water Quality Survey

Items of the water quality survey on existing water sources including the test boreholes are divided into three categories: general, geochemical and sanitary item as shown in Table 6.1.1. As for the test boreholes, more detail results of water quality are described in 5.4.4.

Table 6.1.1 Items of Water Quality Survey on Existing Water Sources

Category	Analysis Item		
General item*	• Temperature • pH	• Electric conductivity	• Salinity
Geochemical item	• Calcium ion • Sodium ion • Nitrite ion • Hardness	• Magnesium ion • Chlorine ion • Bicarbonate ion	• Potassium ion • Sulfate ion • Carbonate ion
Sanitary item	• Escherichia coli (E.Coli)		

*measured by handy type equipment

(2) Locations of Existing Water Sources for Water Quality Survey

After an analysis of well information and inventory survey results on existing water sources, four locations on average including existing well, test borehole and surface water source in some cases, which have different conditions each other, were selected for the water quality survey in each targeted commune. As a rule, the number of the selected locations are 96 (= four location x 24 communes) in total and their locations are shown in Figure 6.1.1 to Figure 6.1.9.

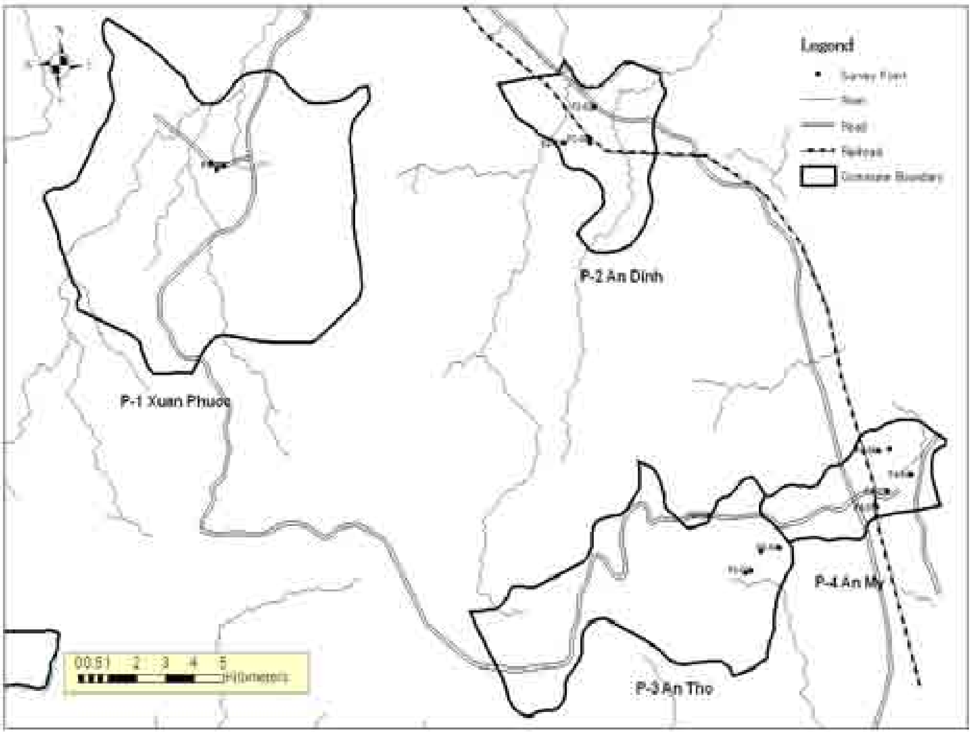


Figure 6.1.1 Survey Location of Water Quality on Existing Water Sources in Phu Yen Province (1)

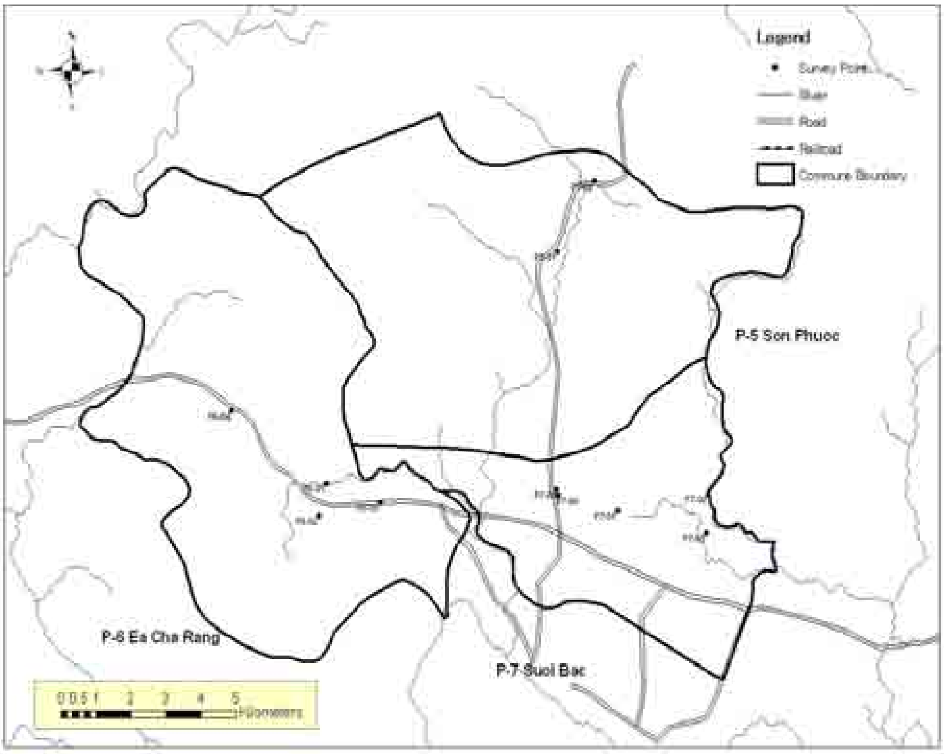


Figure 6.1.2 Survey Location of Water Quality on Existing Water Sources in Phu Yen Province (2)

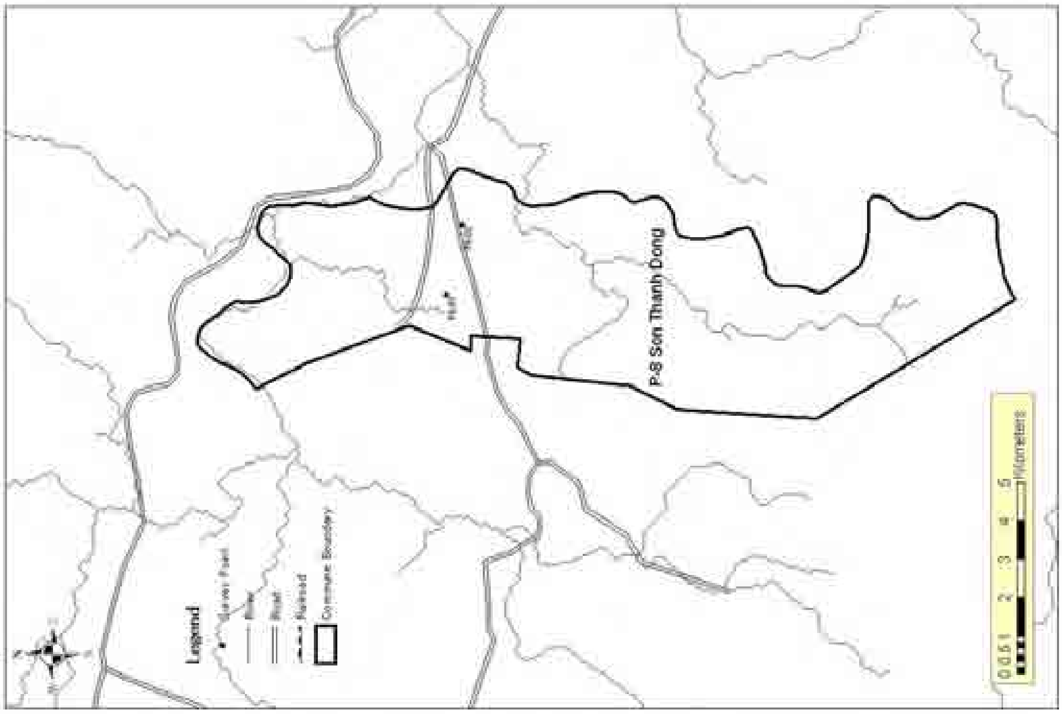


Figure 6.1.3 Survey Location of Water Quality on Existing Water Sources in Phu Yen Province (3)

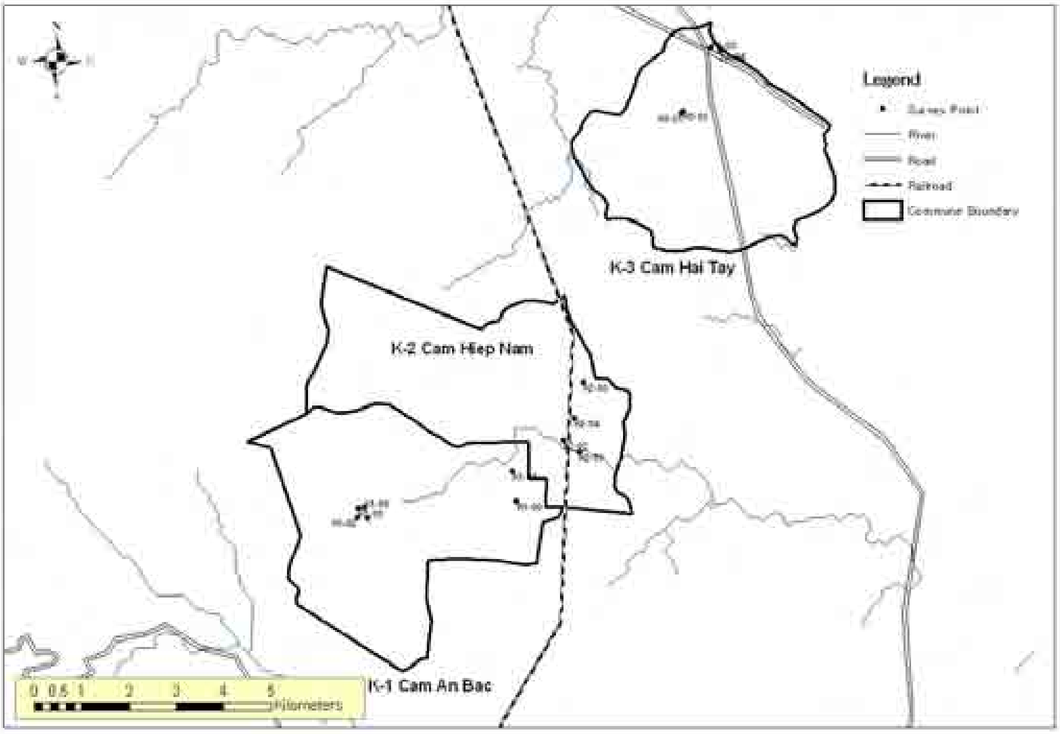


Figure 6.1.4 Survey Location of Water Quality on Existing Water Sources in Khanh Hoa

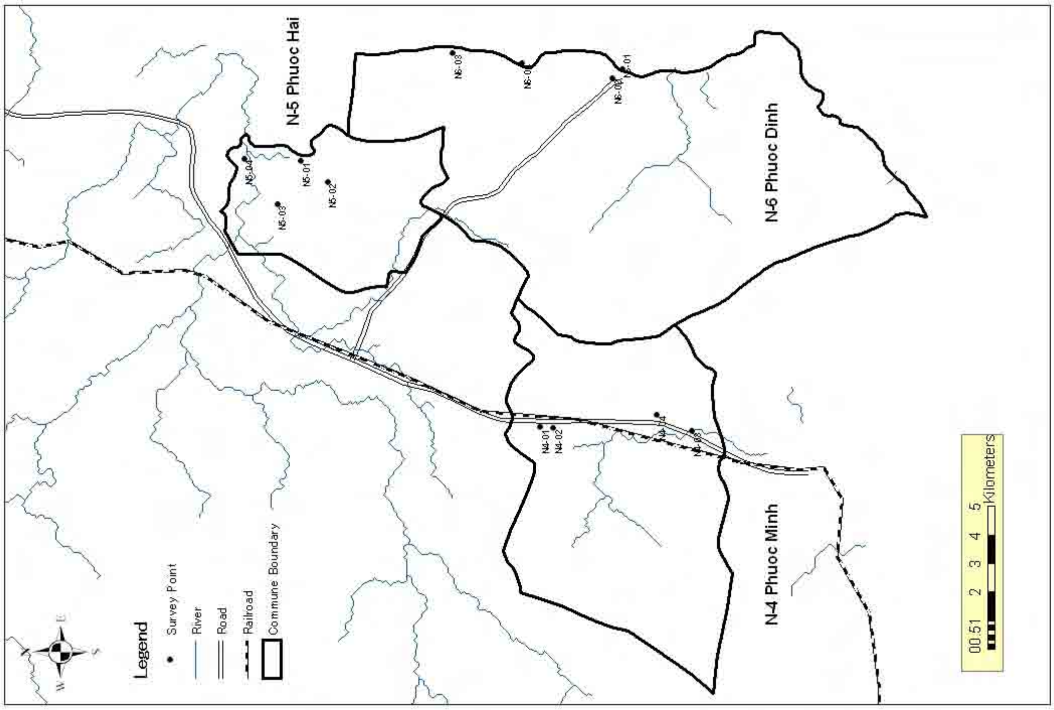


Figure 6.1.5 Survey Location of Water Quality on Existing Water Sources in Ninh Thuan Province (2)

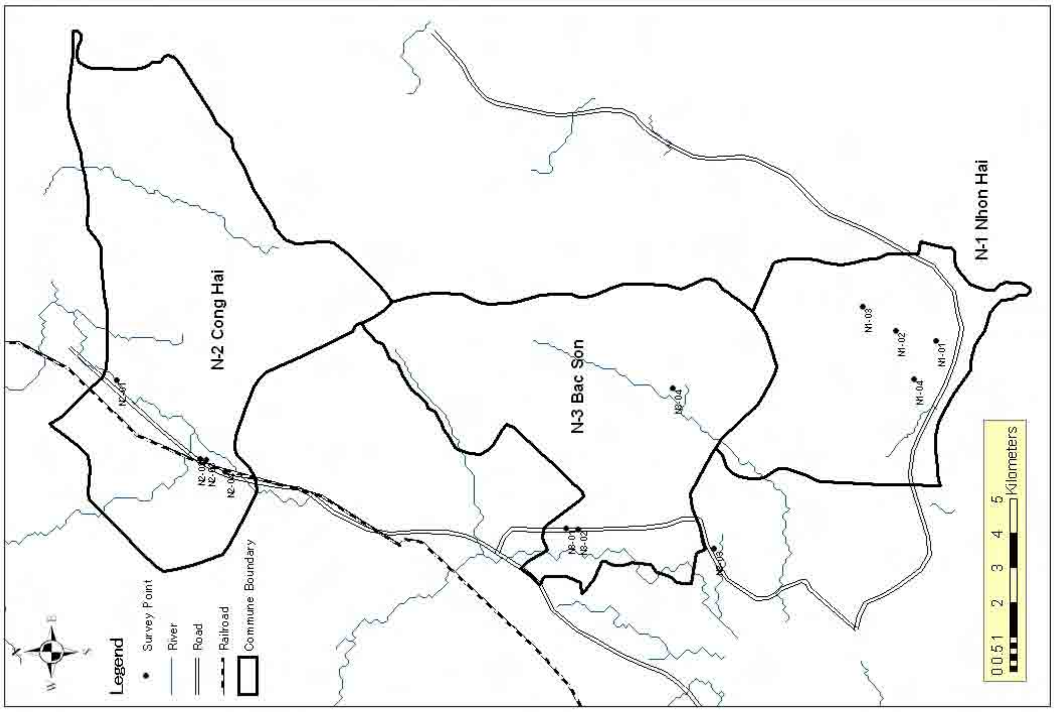


Figure 6.1.6 Survey Location of Water Quality on Existing Water Sources in Ninh Thuan Province (1)

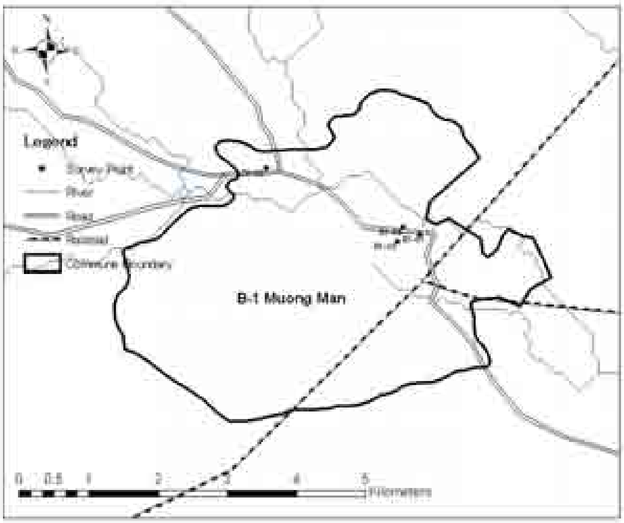


Figure 6.1.7 Survey Location of Water Quality on Existing Water Sources in Binh Thuan Province (1)

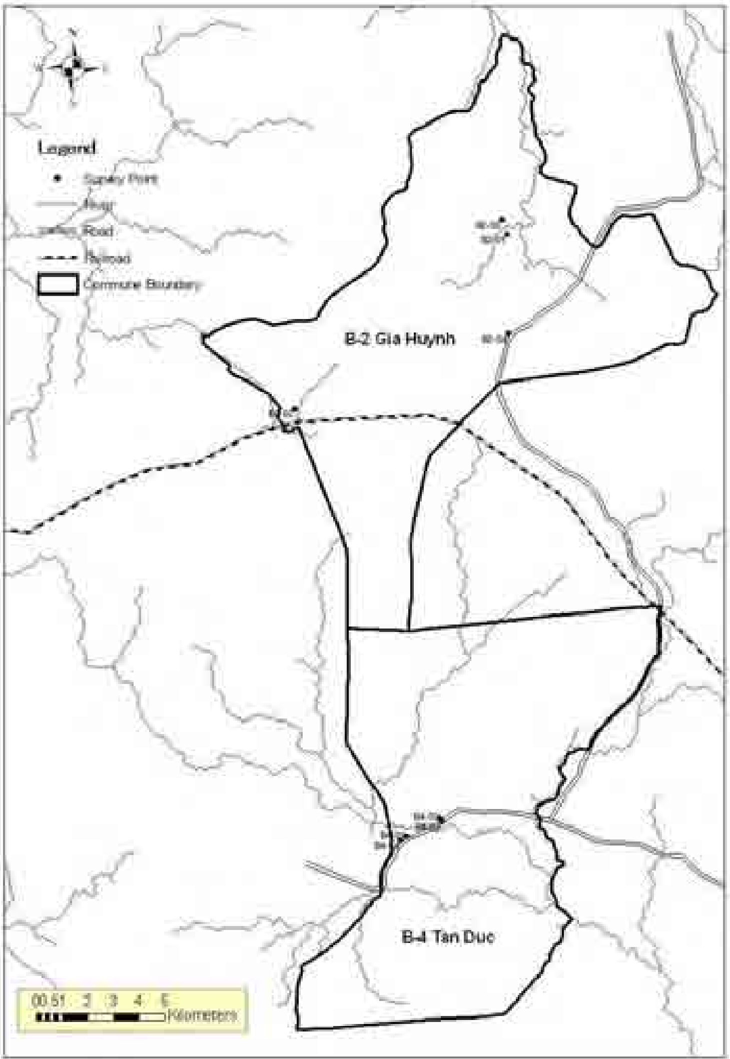


Figure 6.1.8 Survey Location of Water Quality on Existing Water Sources in Binh Thuan Province (2)

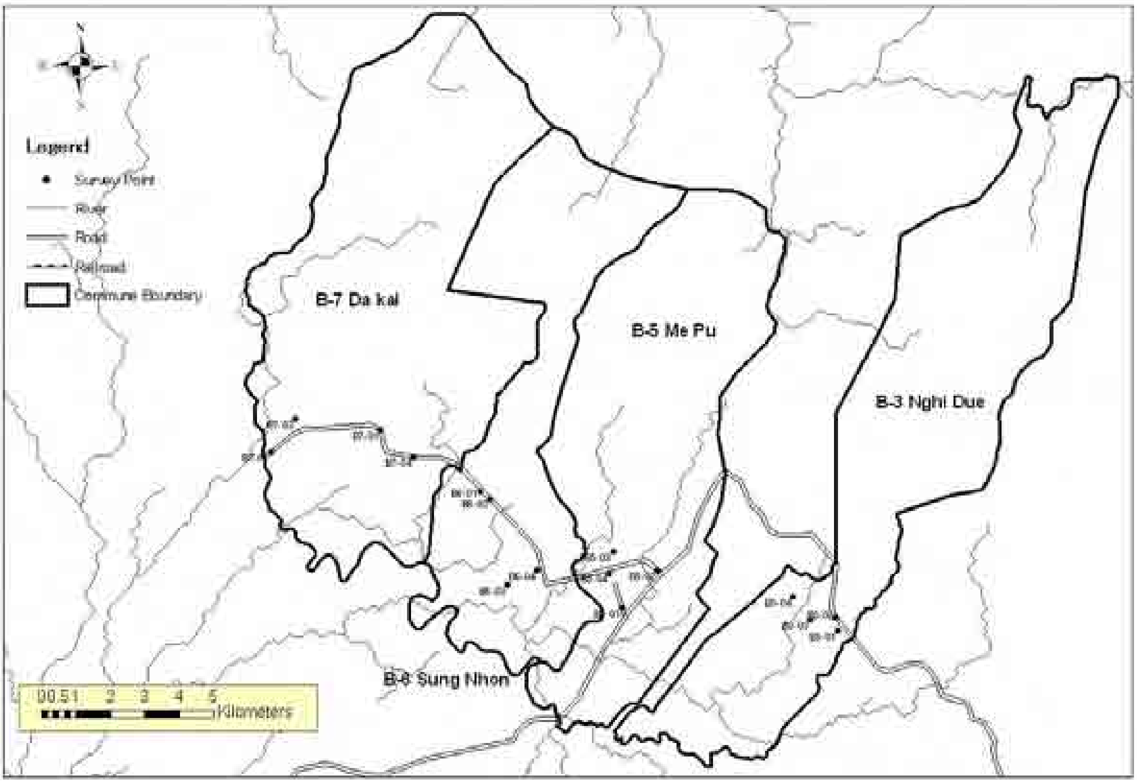


Figure 6.1.9 Survey Location of Water Quality on Existing Water Sources in Binh Thuan Province (3)

(3) Timing of water quality survey on existing water sources

The water quality survey was carried out five times during the Study as shown in Table 6.1.2. The survey was planed to conduct every three month and cover full year. This survey did not include the test boreholes until the second survey because the test boreholes were under construction during the first two surveys.

Table 6.1.2 Timing of Water Quality Survey on Existing Water Sources

Timing / Province	1st.	2nd.	3rd.	4th.	5th.
	Sep. 2007	Dec. 2007	Mar. 2008	Jun. 2008	Sep. 2008
Phu Yen	Rainy S.	Rainy S.	Dry S.	Dry S.	Rainy S.
Khanh Hoa	Rainy S.	Rainy S.	Dry S.	Dry S.	Rainy S.
Ninh Thuan	Rainy S.	Rainy S.	Dry S.	Dry S.	Rainy S.
Binh Thuan	Rainy S.	Dry S.	Dry S.	Rainy S.	Rainy S.

6.1.3 Water Type Analysis

(1) General Tendency of Groundwater Quality

Groundwater generally changes its water quality during flowing in aquifers through following process:

- Elution of components from sediments and rocks.

- Transformation from oxidation condition to reduction condition.
- Ion-exchange between clay minerals and groundwater.

The changes of groundwater quality are divided into three stages as follows.

- First Stage:

Source of groundwater is rainwater, which infiltrates into ground and transforms to groundwater, so that the water quality is similar to distilled water in this stage. At first carbonate mineral in soil and rock is dissolved into groundwater due to the effect of carbon dioxide gas contained in rainwater; as a result, components of Ca^{2+}, Mg^{2+} and HCO_3^- tend to relatively increase. River water at river head area is classified into this stage, which mainly consists of infiltrated and flowed-out rainwater.

- Second Stage:

Components of Na^+ and K^+ tend to increase in succession to Ca^{2+} and Mg^{2+} due to contact with soil and rocks during period of groundwater flowing. Supply source of the components are elution of soil and rock minerals, dissolution of components supplied by decomposition of organic substance and so on. HCO_3^- also increases during the period. Confined groundwater generally belongs to this stage.

- Third Stage:

At third stage, ion exchanges happen between Ca^{2+} and Mg^{2+} in groundwater and Na^+ in clay minerals of soil and rocks, then Ca^{2+} and Mg^{2+} decrease and Na^+ and K^+ increase rapidly. Groundwater, which is far from groundwater recharge area and has little flow ability, belongs to this stage. This kind of groundwater is often found in deep-seated aquifer under alluvial low land and in the aquifer of the Tertiary deposit.

Note: Decomposition of organic substance consumes oxygen in groundwater and the process makes the groundwater to be in reduction condition. Since NO_3 transforms to NH_4 and SO_4^{2-} to H_2S, those components hardly exist in deep aquifers. Therefore, increase or existence of much volume of NO_3^- and/or SO_4^{2-} in deep aquifers means that source of groundwater recharge come from ground surface and the cause will be contamination with fertilizer application. Other possibilities of the increase of those components are effects of geological conditions such as existence of volcanoes, hot springs, mines and so on.

(2) Methodology of Water Type Analysis

With the aim of clarifying water types or recharge conditions of groundwater, hexa diagram and tri-linear diagrams with the major components of water sources: Na+, K+, Ca2+, Mg2+, Cl-, SO42- and HCO3-, were drawn and used in the analysis. Hexa diagram presents dissolved ionic concentration in water as milli equivalents per litter as shown in Figure 6.1.10. Shape of the diagram shows water quality composition and size of it means amount of each ion. On the other hand, tri-linear diagram consist of "Key Diagram", which can present four major components of water and a pair of triangular diagrams, which show ratio of major anion and cation. The former can classify water into five types including "Intermediate Type" and the latter can clearly show component ratio of major ions of water.

1) Hexa Diagram

Hexa diagrams of existing water sources in the target communes are shown in Figure 6.1.11 to Figure 6.1.19. Each diagram consists of two kinds of graphs in order to check seasonal change of water quality. Solid line and broken line shows March 2008 and September 2008 respectively. There is no remarkable seasonal change except for several cases. For example, the test well in Ninh Thuan (N1-TW(Dr)) and the dug well in Ninh Thuan (N4-04(DW)) show extreme change. In the case of N1-TW, groundwater showing type IV (refer to Figure 6.1.10) was affected by seawater intrusion due to pumping test of the test well in March, however, it was cured in September. On the contrary, non-affected water at N4-04(DW) in March was extremely affected by seawater intrusion in September because of over groundwater exploitation by water vender.

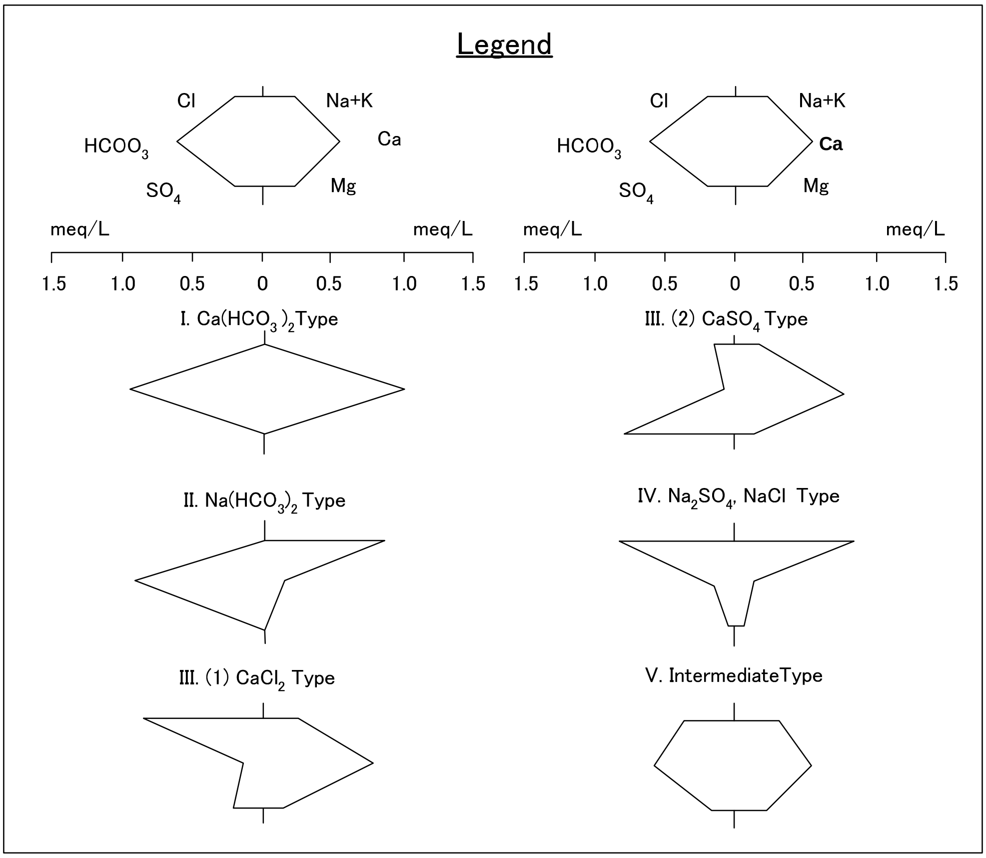


Figure 6.1.10 Water Type Classification by Hexa Diagram

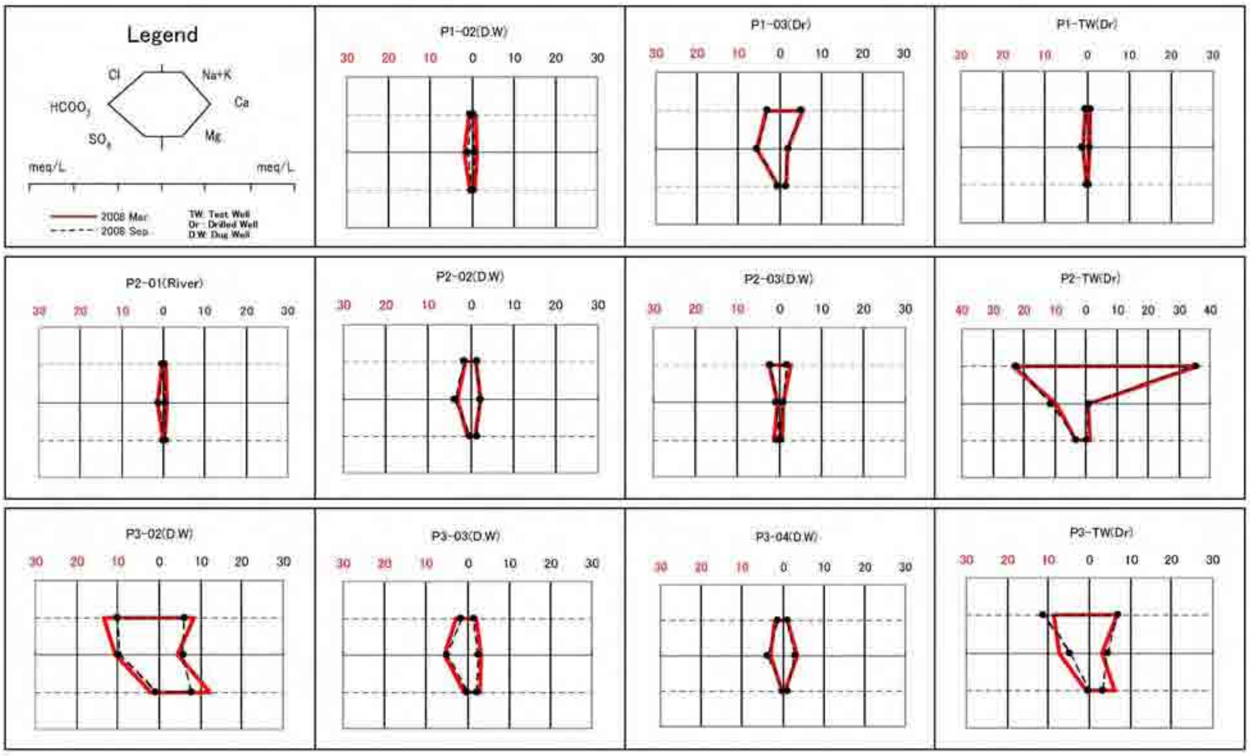


Figure 6.1.11 Hexa Diagram of Existing Water Sources in Target Communes (1)

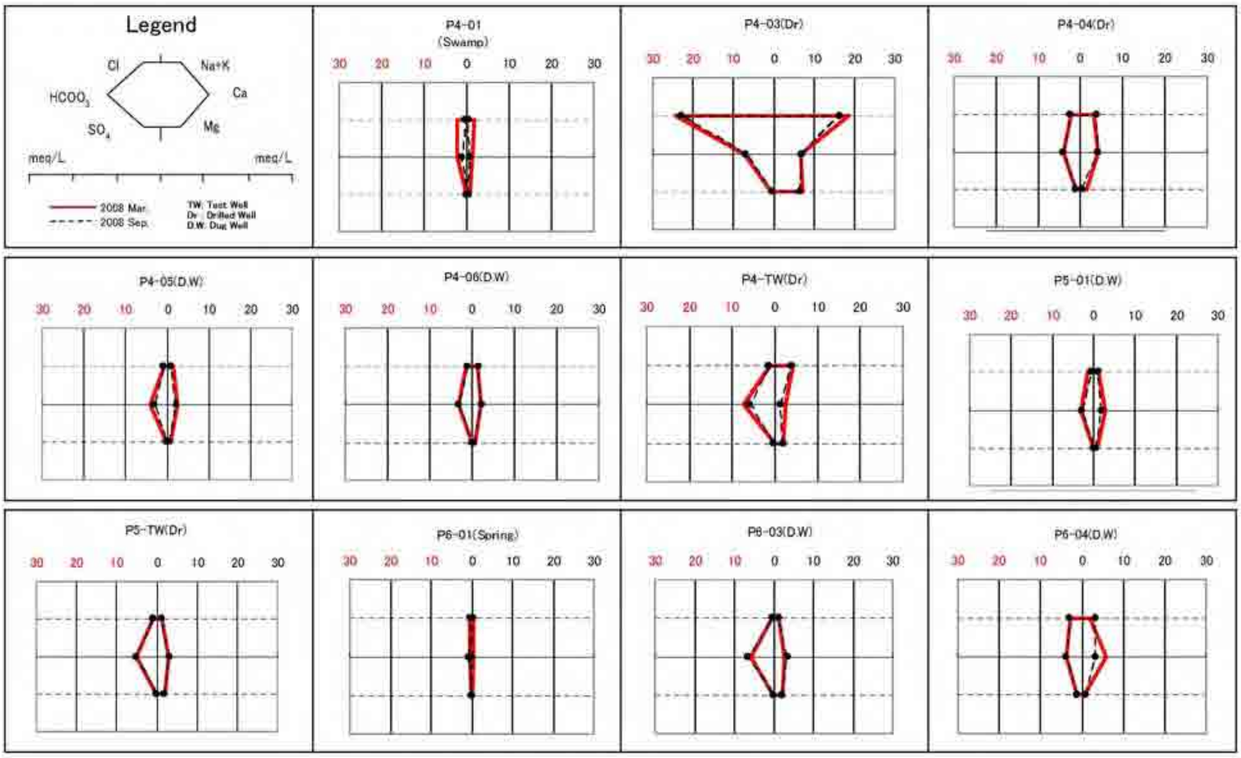


Figure 6.1.12 Hexa Diagram of Existing Water Sources in Target Communes (2)

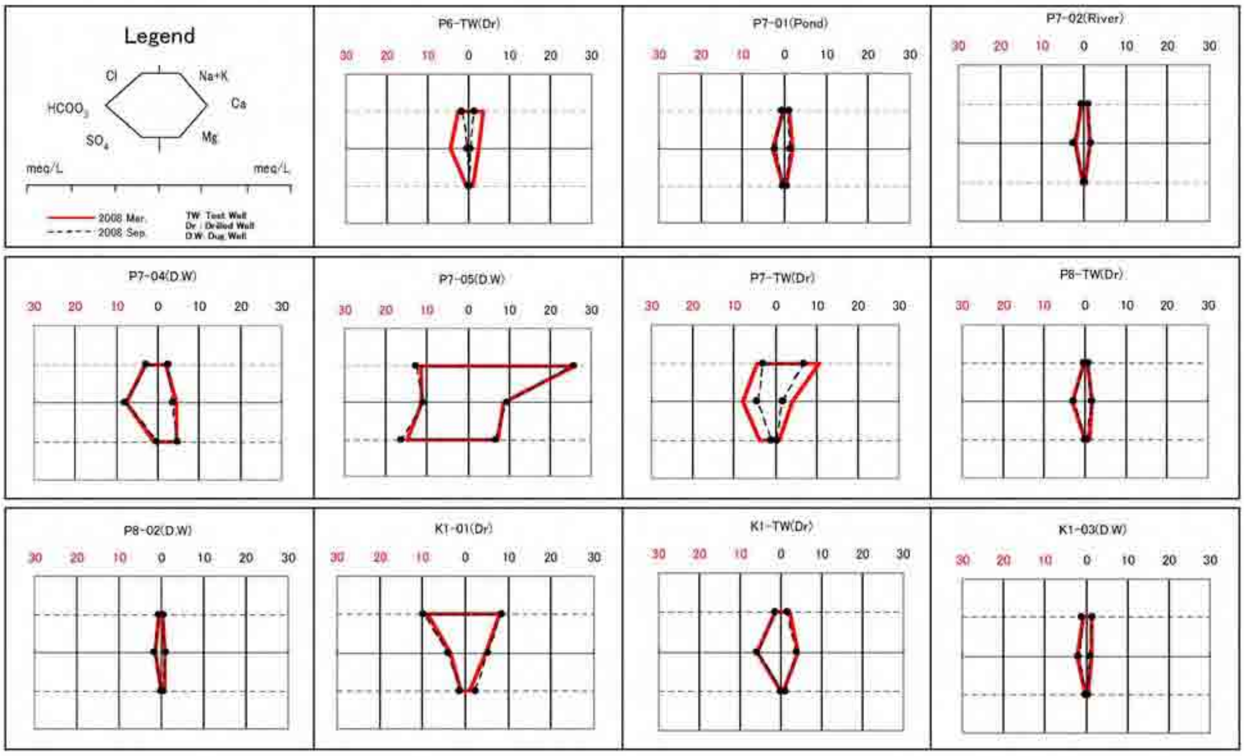


Figure 6.1.13 Hexa Diagram of Existing Water Sources in Target Communes (3)

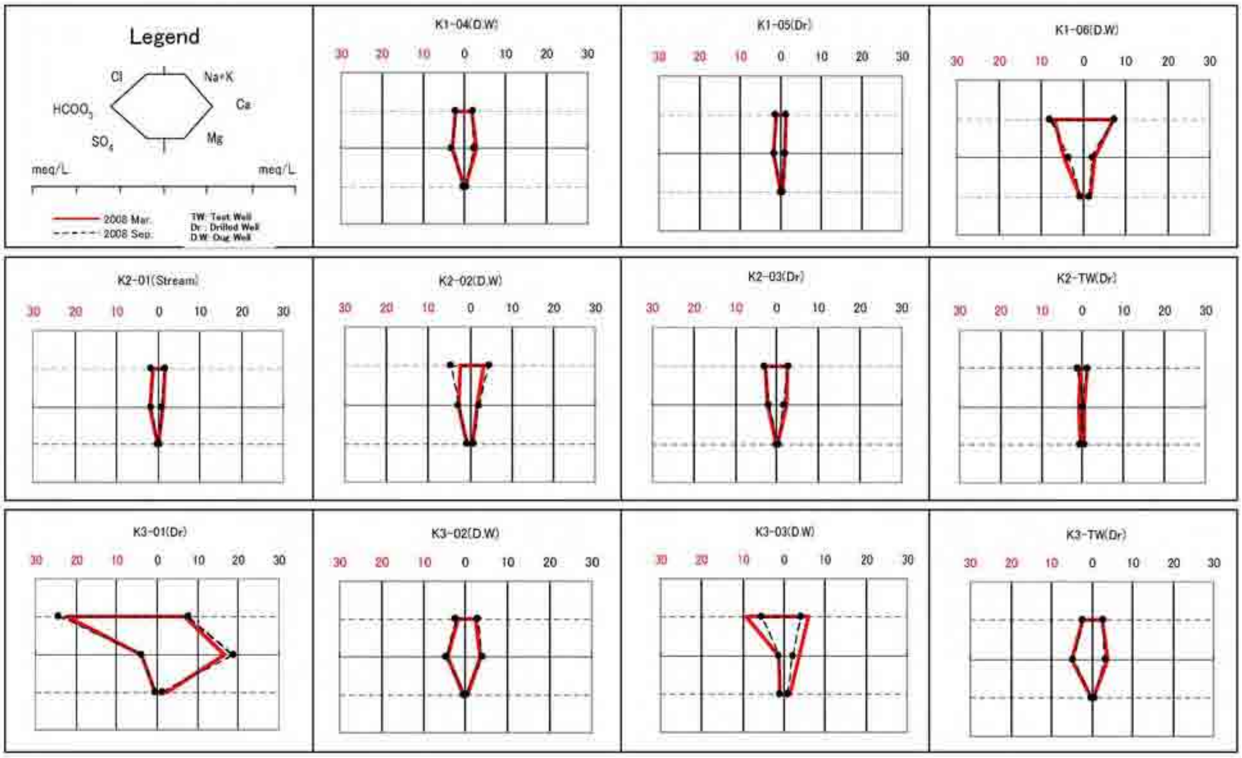


Figure 6.1.14 Hexa Diagram of Existing Water Sources in Target Communes (4)

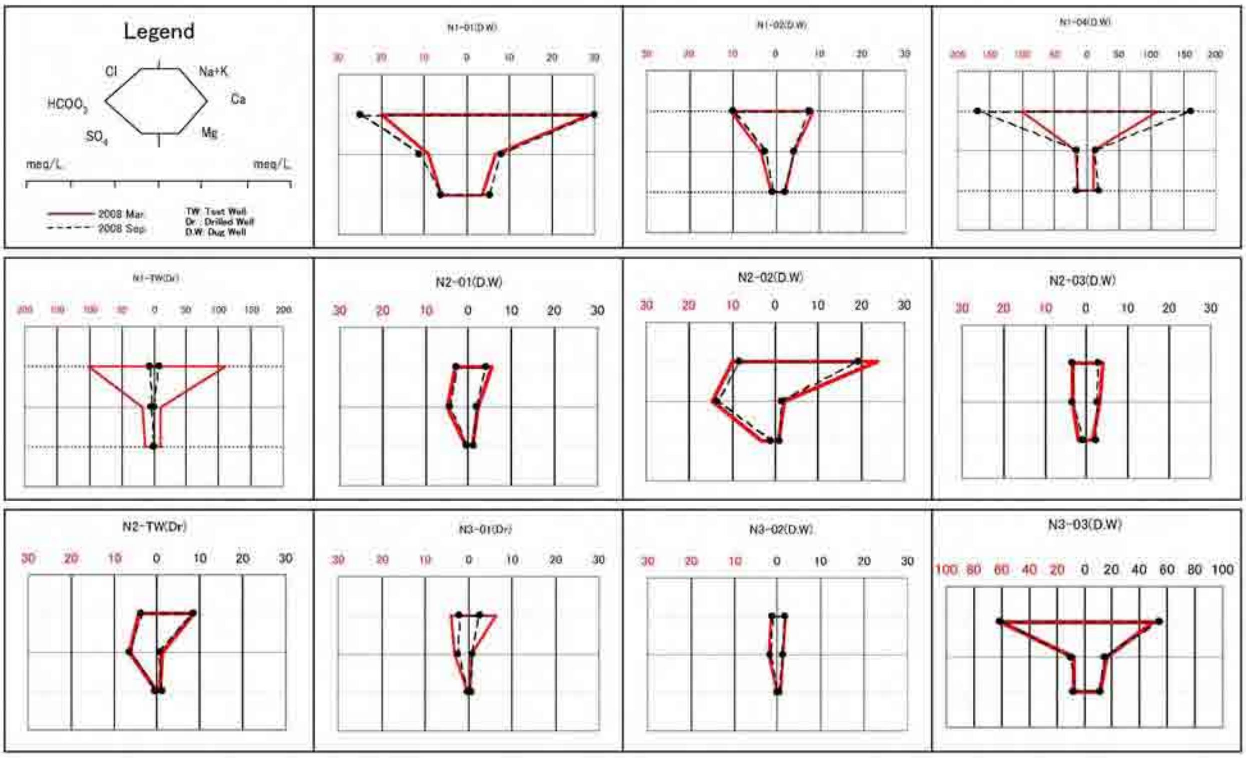


Figure 6.1.15 Hexa Diagram of Existing Water Sources in Target Communes (5)

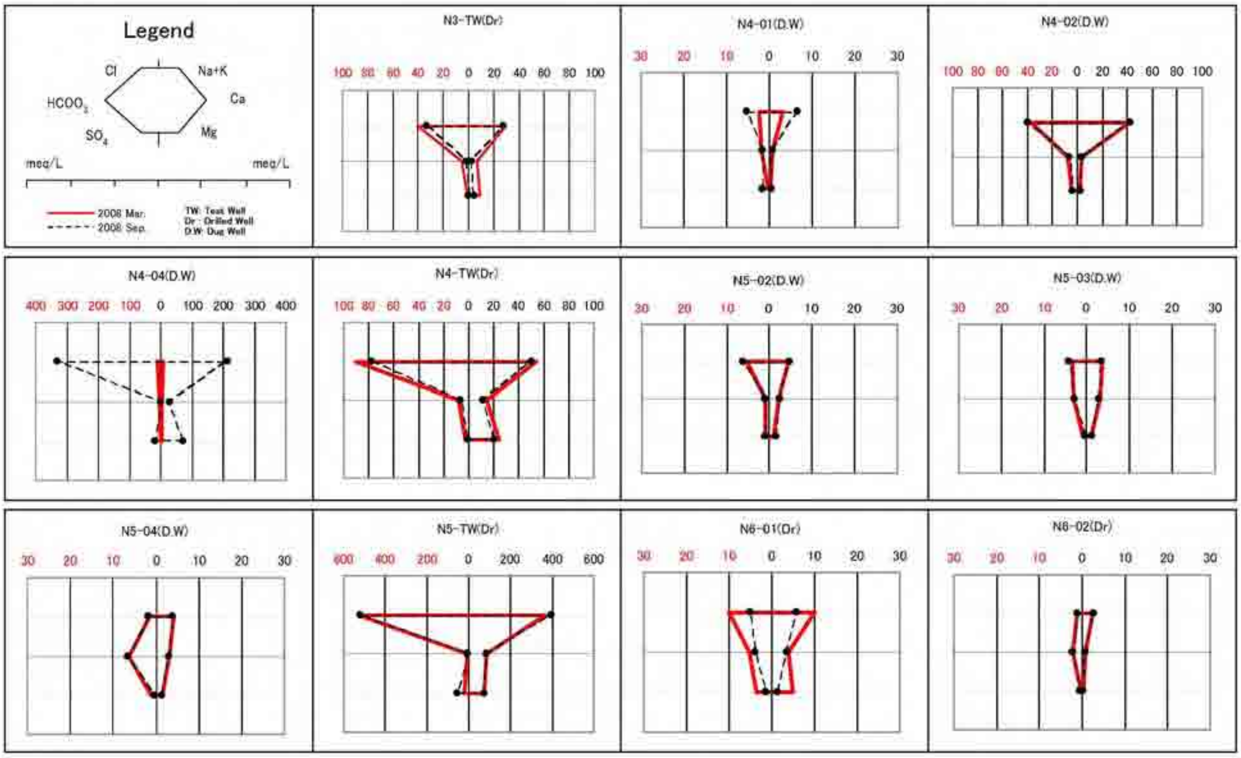


Figure 6.1.16 Hexa Diagram of Existing Water Sources in Target Communes (6)

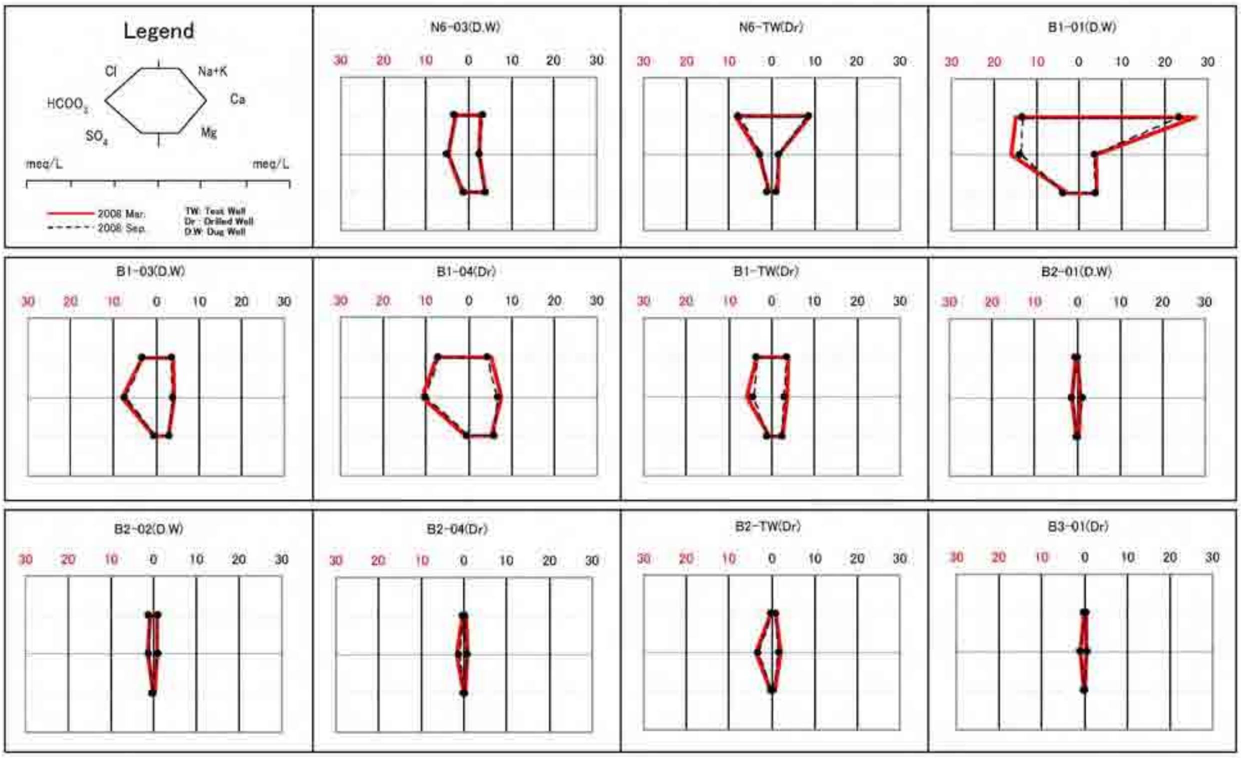


Figure 6.1.17 Hexa Diagram of Existing Water Sources in Target Communes (7)

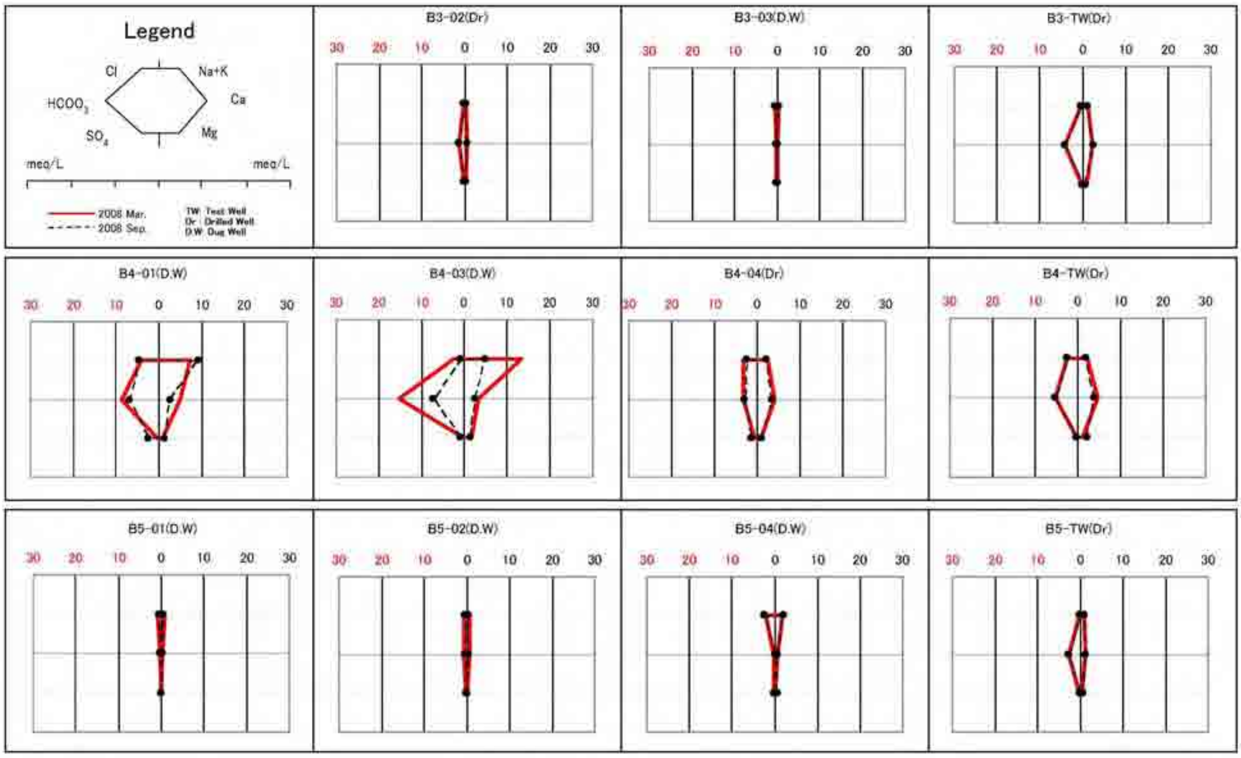


Figure 6.1.18 Hexa Diagram of Existing Water Sources in Target Communes (8)

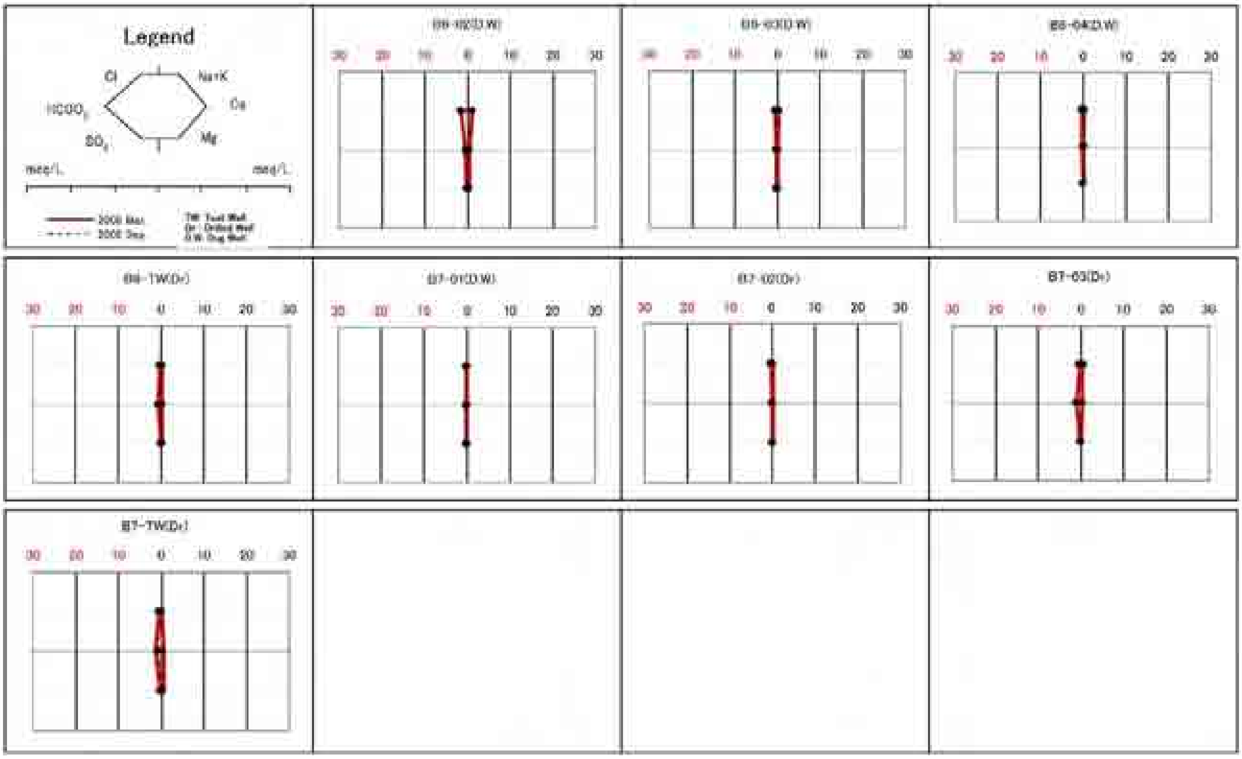


Figure 6.1.19 Hexa Diagram of Existing Water Sources in Target Communes (9)

2) Tri-liner Diagram

Tri-linear diagram was applied in order to classify water type of water sources in the target communes more precisely. Key diagram can identify five kinds of water type as shown in Figure 6.1.20 and descried below.

- Type I: $Ca(HCO_3)_2$ type
  River water and circularity groundwater fall under this type. Groundwater in limestone area is typical example.

- Type II: $Na(HCO_3)_2$ type
  Unsalted confined groundwater which is stagnating under relatively deep from ground surface is classified into this type.

- Type III: $CaSO_4$, $CaCl_2$ type
  Hot spring, mineral spring and salted fossil water correspond to this type. In the case of river water or groundwater, it is possible to be contaminated with hot spring or polluted by industrial wastewater.

- Type IV: NaCl, Na_2SO_4 type
  Seawater or groundwater and hot spring contaminated by seawater are classified into this type.

Groundwater affected by seawater intrusion in the study area corresponds to this type.

- Type V: Intermediate type

This type is intermediate of each type above mentioned. Many of river water, river-bed water and circularity groundwater are classified into Type V.

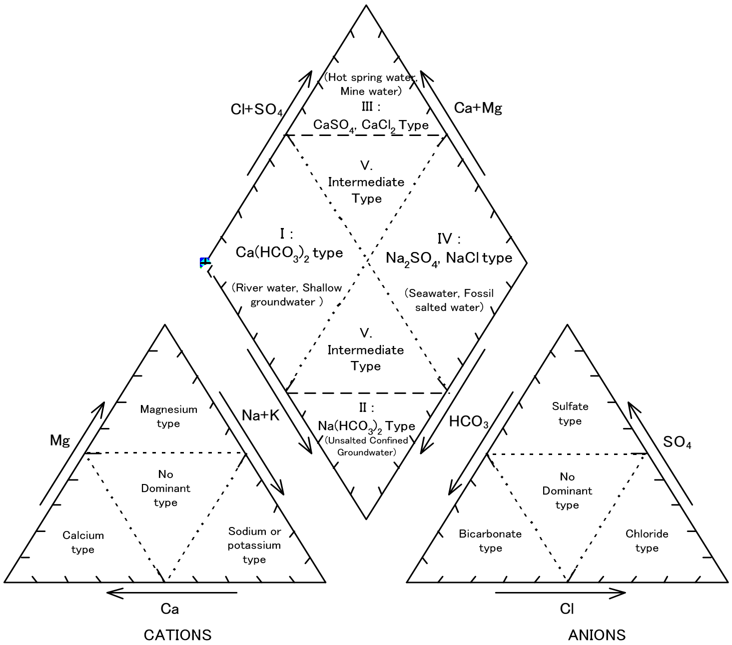


Figure 6.1.20 Water Type Classification by Tri-linear Diagram

Source: Partially reformed "Ground-Water Quality" by USGS: (http://pubs.usgsgov/wri/wri0245045/htms/report2.htm)

a) Existing Water Sources

Tri-linear diagrams of existing water sources, which are mainly groundwater, by each target province are shown in Figure 6.1.21. Differences of water type among four provinces are clearly found as descried below.

- Phu Yen Province

Both groundwater and surface water belong to I type ($Ca(HCO_3$ type) with no impact by seawater intrusion, except several dugwells and swamps near shoreline.

- Khanh Hoa Province

In comparison with Phu Yen province, water type of each water source in Khanh Hoa province is shifted from I type ($Ca(HCO_3$ type) to IV type (Na_2SO_4, NaCl type). This indicates that existing wells near shoreline in Khanh Hoa are affected by seawater intrusion.

- Ninh Thuan Province

Most of all wells in Ninh Thuan province belong to IV type. It seems to be most severely affected by seawater intrusion among four provinces.

- Binh Thuan Province

Water type of each water source in Binh Thuan province is distributed in all four types, because water sources are located in inland. Since the surveyed communes except B-1 are located at more than 50m elevation, salinity of wells in type IV is not caused by seawater intrusion but other reasons.

Tri-linear diagram of each target commune is shown in Figure 6.1.21 to Figure 6.1.27.

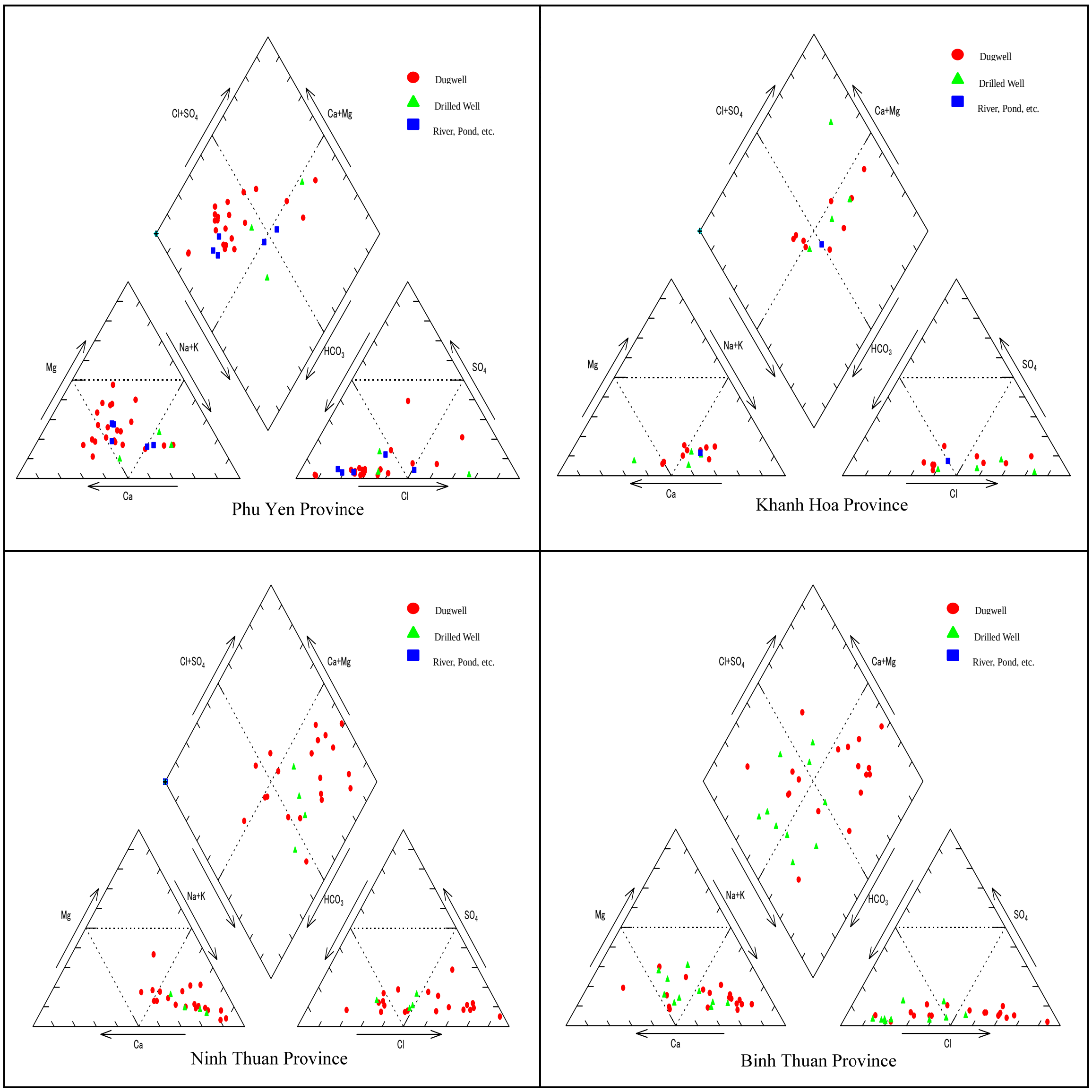


Figure 6.1.21 Tri-linear Diagrams of each Water Sources in Four Provinces

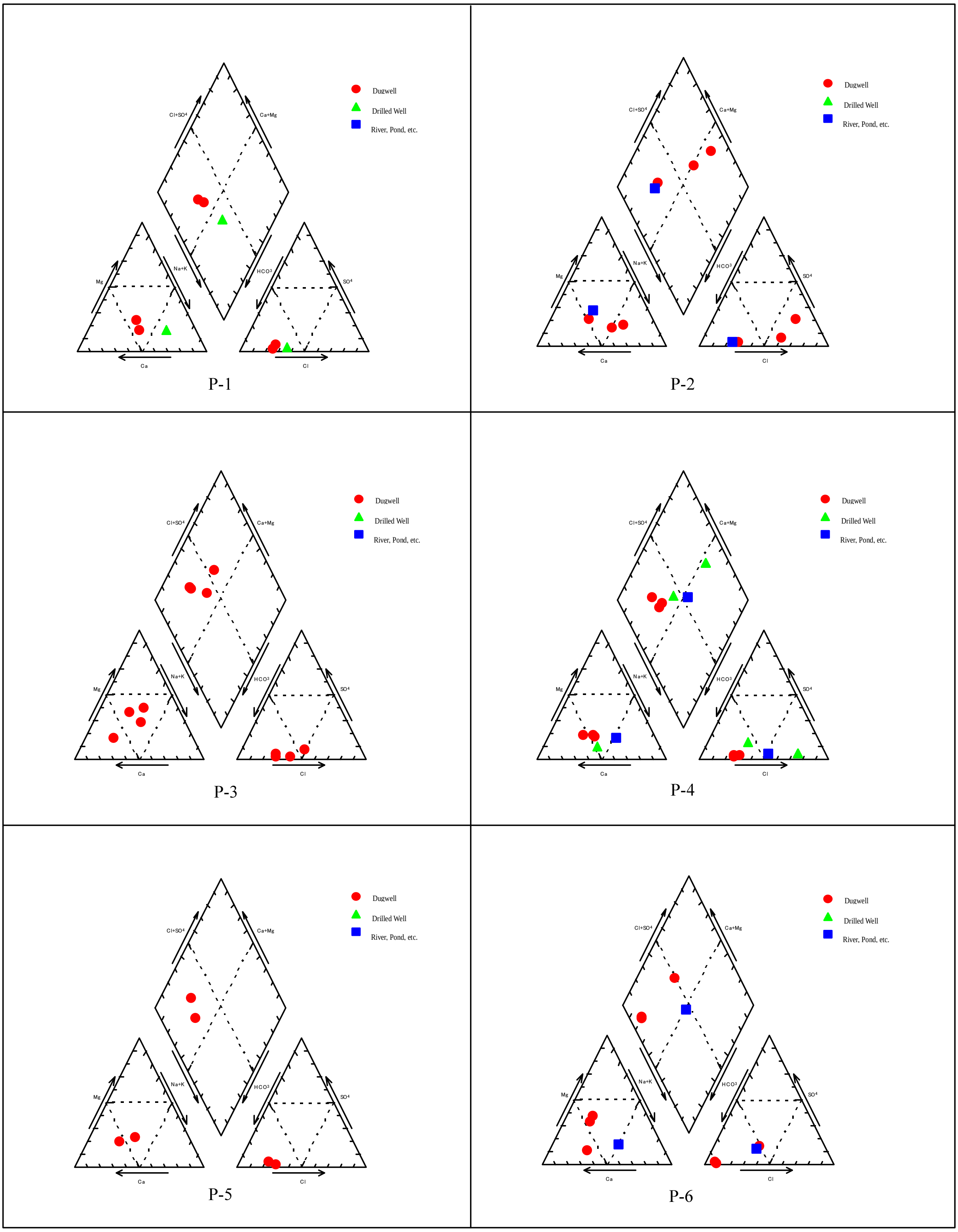


Figure 6.1.22 Tri-linear Diagrams by Target Commune in Phu Yen Province (1)

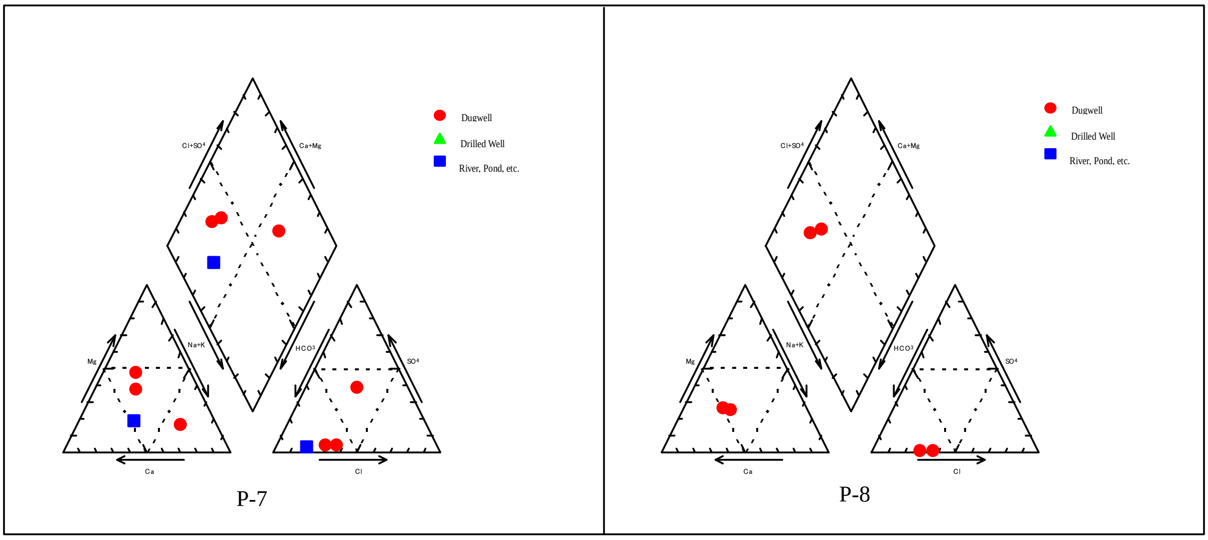


Figure 6.1.23 Tri-linear Diagrams by Target Commune in Phu Yen Province (2)

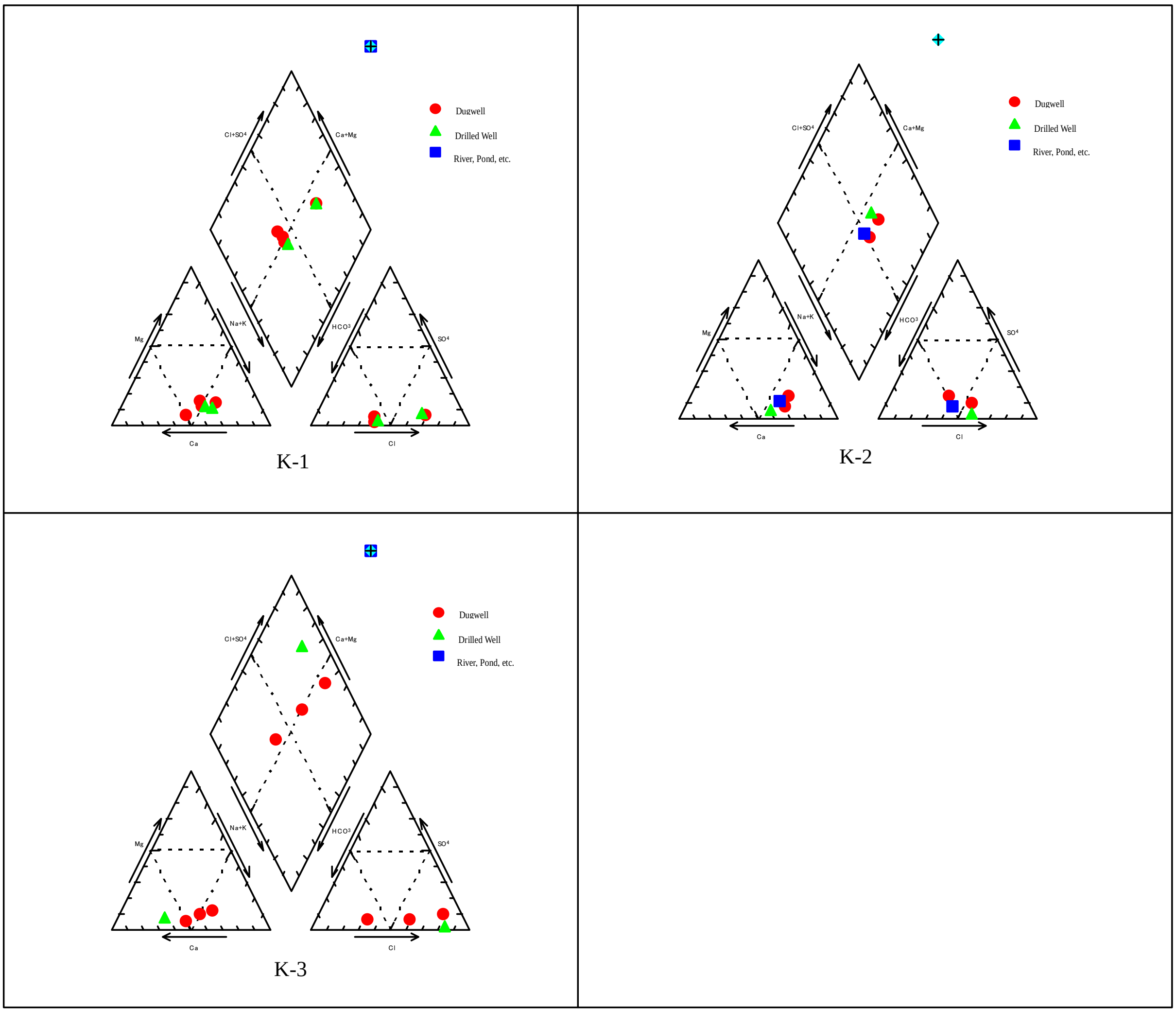


Figure 6.1.24 Tri-linear Diagrams by Target Commune in Khanh Hoa Province

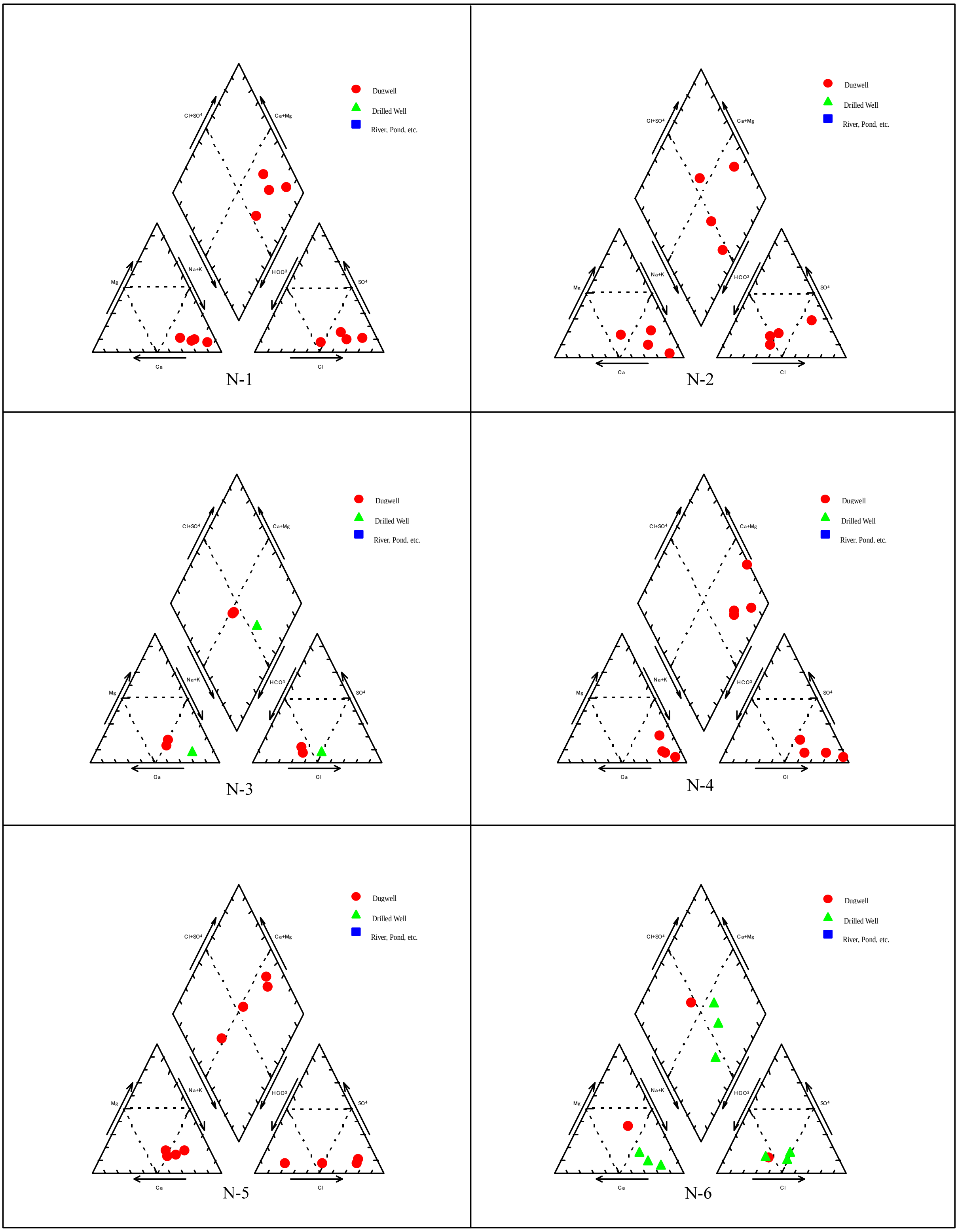


Figure 6.1.25 Tri-linear Diagrams by Target Commune in Ninh Thuan Province

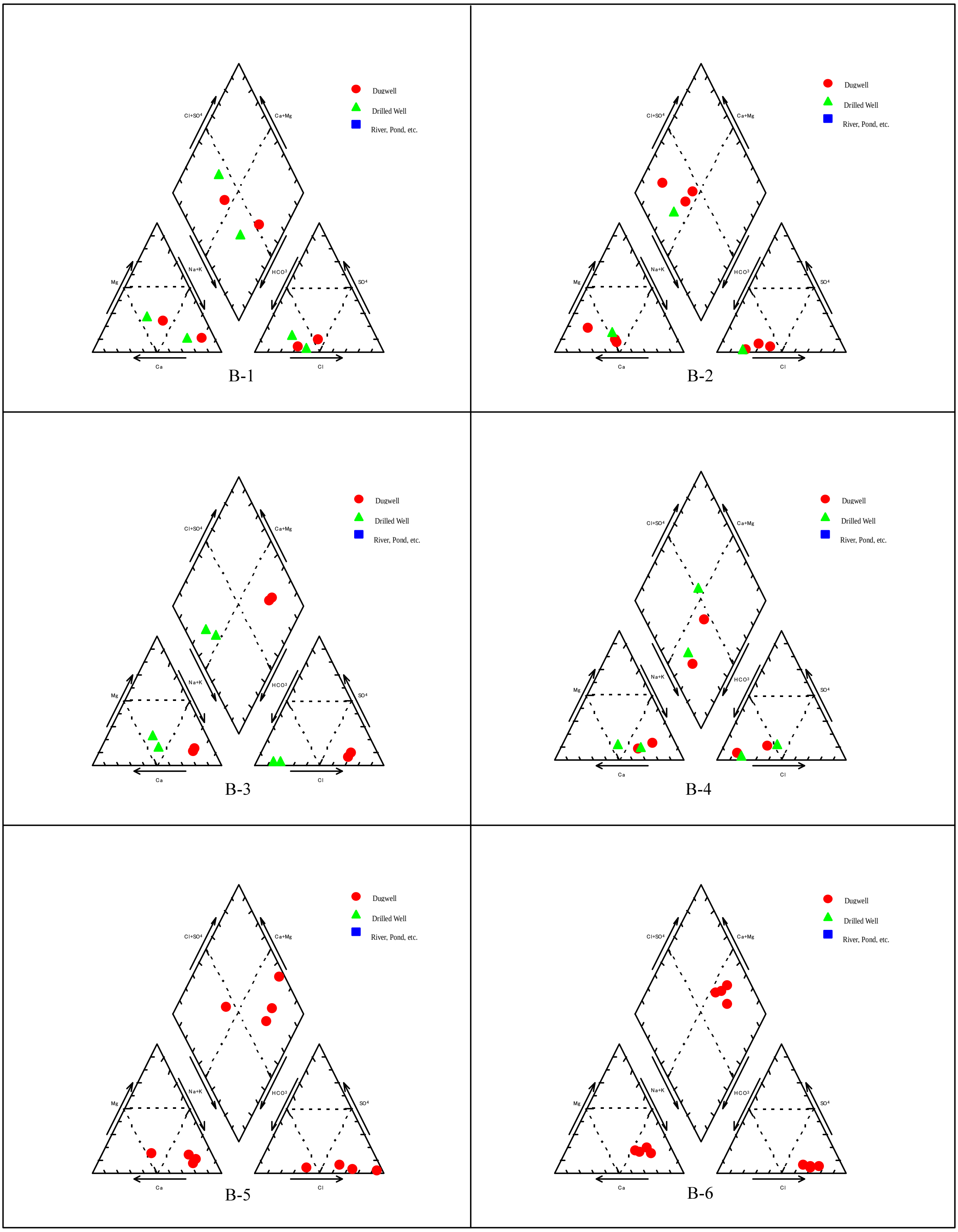


Figure 6.1.26 Tri-linear Diagrams by Target Commune in Binh Thuan Province (1)

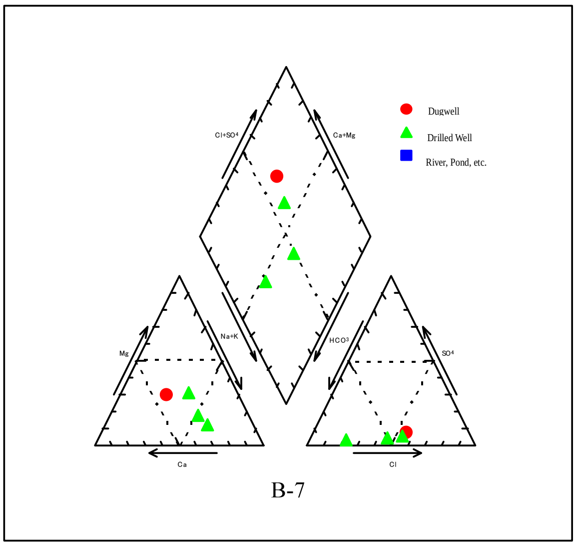


Figure 6.1.27 Tri-linear Diagrams byTarget Commune in Binh Thuan Province (2)

b) Test Boreholes

Tri-linear diagrams of 24 test wells are shown in Figure 6.1.28. Several test wells of Phu Yen and Khanh Hoa province, and all of Binh Thuan province are classified into Type-I. Most of all in Ninh Thuan and three in Phu Yen and one in Khan Hoa belong to Type-IV. Others are Type V. This tendency is almost same as the case of existing water sources.

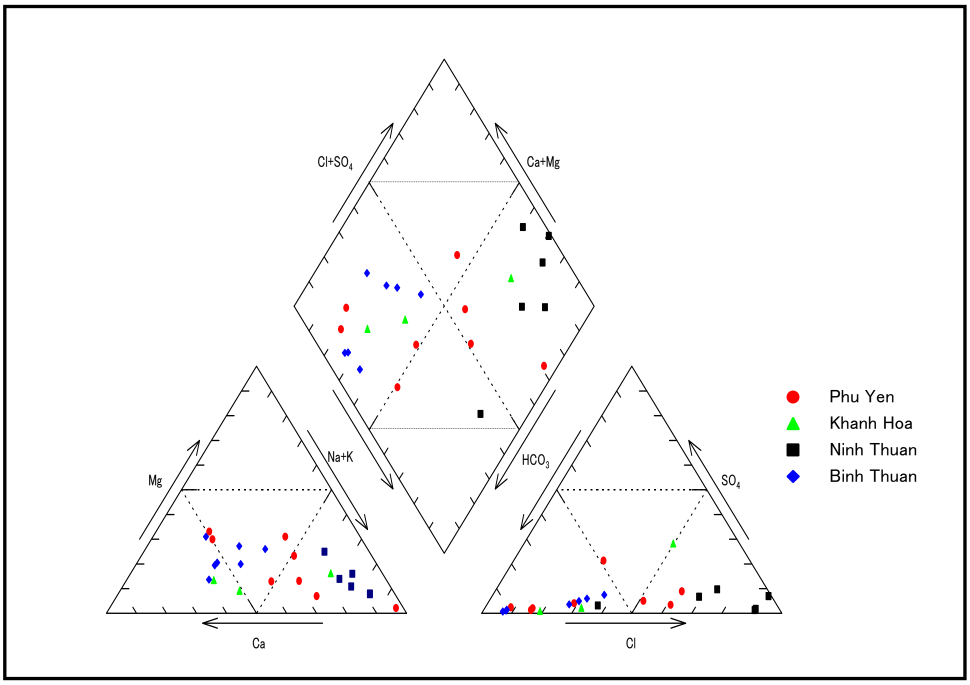


Figure 6.1.28 Tri-linear Diagrams of Test Boreholes

(3) Consideration on Groundwater Recharge

Water type and salinity condition of all survey points in this study is shown in Table 6.1.3 to Table 6.1.5 and summarized in Table 6.1.6. The results of consideration are described below.

1) Phu Yen Province

Although a swamp in P-4 commune seems to be slightly affected by seawater intrusion, most of all surface water in this province is categorized into Type-I and there is no impact of seawater intrusion. As to groundwater, dugwells penetrated into the shallowest aquifer are also fall into Type-I because the aquifer is mainly recharged with rainwater or river water. Dugwell P7-05 is classified into Type-IV having chloride concentration of 390mg/l, however it is not as a result of seawater intrusion because the elevation of ground surface is approximately 60m A.S.L. Three test wells out of eight in this province are classified into Type IV. According to chloride concentration, only P2-TW, which is located in lowland at 9.0m A.S.L, is affected by seawater intrusion because the well reaches to the wedge.

2) Khanh Hoa Province

Stream water in K2 commune is fall into Type IV; however affection of seawater intrusion seems to be small since the concentration of chloride is 50ml/l only. Many of existing drilling wells and dugwells in this province are Type IV and an existing drilling well: K3-01 is the only case of Type III. Since the aquifer of two test wells: K1-TW and K3-TW, is not layer aquifer but fissure aquifer in the basement rocks, they have no influence of seawater intrusion at all.

3) Ninh Thuan Province

There is most severe impact by seawater intrusion among four provinces. Most of all existing wells are fall into Type IV and five out of six test wells in Ninh Thuan province are also Type IV. Furthermore, the chloride concentration of them is extremely higher than other provinces.

4) Binh Thuan Province

All test wells and existing drilling wells are classified into Type I which means the “First Stage” of groundwater recharge process. On the other hand, many dugwells of this province are Type IV, however their chloride concentration are very low except B1-01. With taking their elevation: more than 100m A.S.L, into consideration, the cause is not seawater intrusion but elution of salinity from geological formations under the groundwater recharge process.

Table 6.1.3 Water Type and Chloride Concentration (1)

*Point No.	Commun Name	**Distance from Shoreline (km)	Altitude (m)	***Water Type	Average of Chloride (mg/l)	****Source Type
P1-01	Xuan Phuoc	22	24.1	I	46.1	DW
P1-02			21.0	I	15.1	DW
P1-03			19.6	V	117.0	DR
P1-TW			17.2	I	16.0	DR
P2-01	An Dinh	6	9.5	I	15.1	River
P2-02			8.4	I	54.1	DW
P2-03			19.9	IV	77.6	DW
P2-04			11.9	V	58.5	DW
P2-TW			9.0	IV	820.1	DR
P3-01	An Tho	6	81.6	I	210.9	DW
P3-02			85.7	V	396.4	DW
P3-03			83.4	I	78.4	DW
P3-04			105.2	I	56.0	DW
P3-TW			84.2	V	352.2	DR
P4-01	An My	2	4.8	IV	95.0	Swamp
P4-02			324.8	I	27.5	DW
P4-03			5.6	IV	784.2	DR
P4-04			11.4	I	77.3	DR
P4-05			24.4	I	40.4	DW
P4-06			10.8	I	42.5	DW
P4-TW			12.5	V	44.9	DR
P5-01	Son Phuoc	22	158.2	I	45.7	DW
P5-02			166.2	I	14.2	DW
P5-TW			145.5	I	35.5	DR
P6-01	Ea Cha Rang	34	150.8	I	11.0	Spring
P6-02			171.3	I	11.5	DW
P6-03			158.1	I	14.2	DW
P6-04			182.3	I	86.2	DW
P6-TW			182.8	IV	70.9	DR
P7-01	Suoi Bac	28	96.8	I	17.7	Pond
P7-02			62.4	I	20.2	River
P7-03			134.0	I	149.8	DW
P7-04			136.4	I	124.4	DW
P7-05			59.2	IV	390.3	DW
P7-TW			59.2	IV	145.9	DR
P8-01	Son Thanh Dong	24	56.0	I	21.3	DW
P8-02			51.3	I	18.8	DW
P8-TW			45.5	I	10.0	DR
K1-01	Cam An Bac	8	67.8	IV	378.6	DR
K1-02			68.0	V	78.0	DW
K1-03			71.2	I	47.5	DW
K1-04			46.0	IV	69.8	DW
K1-05			73.0	V	44.0	DR
K1-06			40.8	IV	424.4	DW
K1-TW			57.8	I	48.5	DR
K2-01	Cam Hiep Nam	6	29.9	IV	49.6	Stream
K2-02			35.0	IV	163.4	DW
K2-03			44.5	IV	105.3	DR
K2-04			35.2	IV	43.4	DW

Table 6.1.4 Water Type and Chloride Concentration

*Point No.	Commun Name	**Distance from Shoreline (km)	Altitude (m)	***Water Type	Average of Chloride (mg/l)	****Source Type
K2-TW			43.2	IV	31.9	DR
K3-01	Cam Hai Tay	2	20.0	III	709.1	DR
K3-02			20.0	I	66.3	DW
K3-03			10.4	IV	295.7	DW
K3-04			5.0	V	234.0	DW
K3-TW			19.9	I	82.1	DR
N1-01	Nhon Hai	2	7.8	IV	795.6	DW
N1-02			16.7	IV	354.2	DW
N1-03			29.0	IV	354.5	DW
N1-04			3.5	IV	3,803.4	DW
N1-TW			17.2	IV	1,348.4	DR
N2-01	Cong Hai	3	6.6	V	104.9	DW
N2-02			13.0	V	327.6	DW
N2-03			14.4	V	119.1	DW
N2-04			14.8	IV	75.3	DW
N2-TW			10.2	V	141.8	DR
N3-01	Bac Son	3	19.2	IV	104.9	DR
N3-02			20.4	V	44.3	DW
N3-03			10.8	IV	2,155.5	DW
N3-04			40.6	V	64.7	DW
N3-TW			18.6	IV	1,278.7	DR
N4-01	Phuoc Minh	4	30.9	IV	128.3	DW
N4-02			33.0	IV	1,345.8	DW
N4-03			11.0	IV	280.1	DW
N4-04			21.1	IV	3,223.4	DW
N4-TW			40.5	IV	2,984.0	DR
N5-01	Phuoc Dinh	3	6.8	IV	498.1	DW
N5-02			10.9	IV	194.6	DW
N5-03			10.0	IV	120.2	DW
N5-04			5.0	I	58.1	DW
N5-TW			8.9	IV	18,553.7	DR
N6-01	Phuoc Hai	0.5	6.4	IV	236.0	DR
N6-02			21.2	V	41.1	DR
N6-03			6.6	I	109.9	DW
N6-04			7.6	IV	109.0	DR
N6-TW			58.0	IV	295.4	DR
B1-01	Muong Man	8	21.4	IV	460.2	DW
B1-02			27.2	V	102.8	DR
B1-03			22.4	I	115.6	DW
B1-04			22.9	I	204.2	DR
B1-TW			19.5	I	127.0	DR
B2-01	Gia Huynh	33	124.8	I	11.7	DW
B2-02			118.1	I	34.0	DW
B2-03			120.0	I	26.6	DW
B2-04			138.2	I	11.7	DR
B2-TW			123.4	I	10.0	DR
B3-01	Nghi Duc	47	129.2	I	8.9	DR
B3-02			132.7	I	7.4	DR
B3-03			132.2	IV	17.4	DW

Table 6.1.5 Water Type and Chloride Concentration (3)

*Point No.	Commun Name	**Distance from Shoreline (km)	Altitude (m)	***Water Type	Average of Chloride (mg/l)	****Source Type
B3-04			132.5	IV	23.0	DW
B3-TW			128.1	I	10.6	DR
B4-01	Tan Duc	20	66.7	V	150.0	DW
B4-02			61.0	V	86.9	DR
B4-03			57.4	II	57.1	DW
B4-04			70.2	V	110.6	DR
B4-TW			74.0	I	85.7	DR
B5-01	Me Pu	50	120.2	IV	29.1	DW
B5-02			119.6	I	16.3	DW
B5-03			128.0	IV	17.7	DW
B5-04			123.4	IV	74.5	DW
B5-TW			123.4	I	7.7	DR
B6-01	Sung Nhon	50	120.2	IV	46.1	DW
B6-02			118.0	IV	53.2	DW
B6-03			119.9	IV	16.3	DW
B6-04			120.6	IV	11.7	DW
B6-TW			117.4	I	8.3	DR
B7-01	Da Kai	50	125.8	V	8.9	DW
B7-02			119.6	V	12.4	DR
B7-03			119.7	V	9.2	DR
B7-04			128.8	V	31.9	DR
B7-TW			122.6	I	13.6	DR

*P: Phu Yen, K:Khanh Hoa, N:Ninh Thuan, B:Binh Thuan, TW:Test Well
** Distance from CPC office to shoreline
*Type I: $Ca(HCO_3)_2$ type (River water, Shallow groundwater),**Type II**: $Na(HCO_3)_2$ type (Unsalted Confined Groundwater)
Type III $CaSO_4$, $CaCl_2$ type (Hot spring water, Mine water),**Type IV**: Na_2SO_4, NaCl type (Seawater, Fossil salted water),
Type V: Intermidiate type
*****DW:Dugwell, DR:Drilled Well

>Cl 400mg/l

400> >Cl 250mg/l

Table 6.1.6 Summary of Water Type by Commune and Water Source

Province	Commune No.	Commune	Water Source																			
			Test Borehole					Dug Well					Drilled Well					Surface Water				
			Type I	Type II	Type III	Type IV	Type V	Type I	Type II	Type III	Type IV	Type V	Type I	Type II	Type III	Type IV	Type V	Type I	Type II	Type III	Type IV	Type V
Phu Yen	P-1	Xuan Phuoc	○					2									1					
	P-2	An Dinh				○		1			1	1						1				
	P-3	An Tho					○	3				1										
	P-4	An My					○	3					1			1					1	
	P-5	Son Phuoc	○					2														
	P-6	Ea Cha Rang				○		3										1				
	P-7	Suoi Bac				○		2			1							2				
	P-8	Son Thanh Don	○					2														
	Total		**3**			**3**	**2**	**18**			**2**	**2**	**1**			**1**	**1**	**4**			**1**	
Khan Hoa	K-1	Cam An Bac	○					1			1	1				1	1					
	K-2	Cam Hiep Nam				○					2					1					1	
	K-3	Cam Hai Tay	○					1			1	1			1							
	Total		**2**			**1**		**2**			**4**	**2**			**1**	**2**	**1**				**1**	
Nihn Thuan	N-1	Nhon Hai				○					4											
	N-2	Cong Hai					○				1	3										
	N-3	Bac Son				○						2				1						
	N-4	Phuoc Minh				○					4											
	N-5	Phuoc Hai				○		1			3											
	N-6	Phuoc Dinh				○		1								2	1					
	Total					**5**	**1**	**2**			**12**	**5**				**3**	**1**					
Binh Thuan	B-1	Muong Man	○					1			1		1				1					
	B-2	Gia Huynh	○					3					1									
	B-3	Nghi Duc	○								2		2									
	B-4	Tan Duc	○						1			1					2					
	B-5	Me Pu	○					1			3											
	B-6	Dung Nhon	○								4											
	B-7	Da Kai	○									1					3					
	Total		**7**					**5**	**1**		**10**	**2**	**4**				**6**					

*__Type I:__ $Ca(HCO_3)_2$ type (River water, Shallow groundwater), **Type II**: $Na(HCO_3)_2$ type (Unsalted Confined Groundwater),
Type III $CaSO_4$, $CaCl_2$ type (Hot spring water, Mine water), **Type IV**: Na_2SO_4, NaCl type (Seawater, Fossil salted water), **Type V**: Intermidiate type
**Number means water source number.

(Number means water source number)

6.2 Seawater Intrusion Survey

6.2.1 Purpose of Survey

This survey was conducted to study the current state of seawater intrusion to groundwater along coastal zone in the study area, and to use for the planning of rural water supply system. Salt accumulation issues, which sometimes happen in inland area with no outlet to the sea, were excluded from the objective of this survey. The survey consists of following three steps, namely, 1) preparation, 2) preparatory survey, and 3) detailed survey.

6.2.2 Preparation Work

All of the four target provinces face to the sea so that the preparatory survey area was set in the preparatory work. The possible areas of salinity intrusion will be efficiently identified with the procedure below described.

Possible areas of seawater intrusion in the study area were initially identified using the geomorphology, soil, geology, vegetation and land use characteristics, and elevation data (DEM) obtained from the remote sensing analysis. Figure 6.2.1 is an example of topographical classification map of Ninh Thuan province produced by this procedure. It can easily identify the distribution of low land areas near the coast and the target communes.

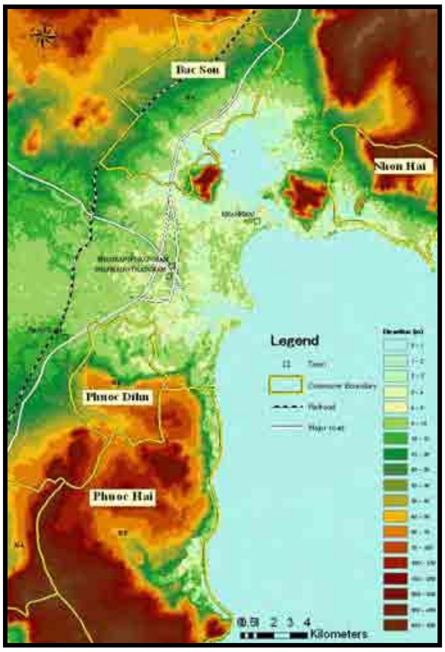


Figure 6.2.1 Topographical Classification of the Central of Ninh Thuan Province and the Location of the Targeted Commune

Seawater intrusion against groundwater is caused not only by natural condition but also by human activities such as pumping groundwater. Therefore, the related information such as existing well inventory and existing survey results of salinity intrusion were examined at first especially on the vulnerability of the target communes against seawater intrusion.

6.2.3 Preparatory Survey

The preparatory survey was conducted for generally understanding the current state of seawater intrusion in the study area based on the preparation work.

(1) Survey points

The survey points of the preparatory survey were selected as shown in Table 6.2.1 and Figure 6.2.2: namely, 22 block and 500 survey points in total. They were selected from the coastal plains where were lower than 20 m A.S.L (above seawater level). The survey blocks were generated by DEM data analysis.

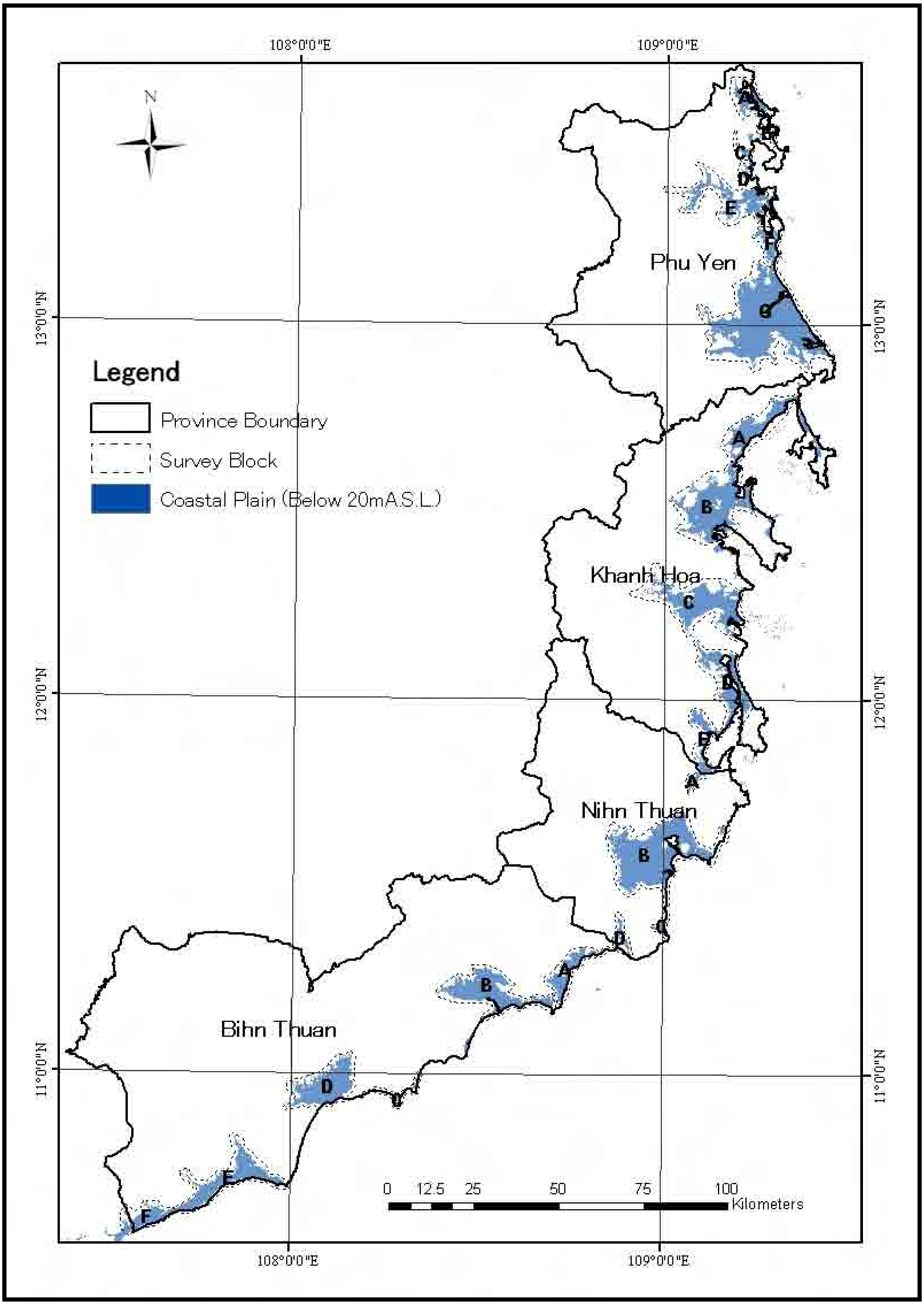


Figure 6.2.2 Survey Blocks for Preparatory Suvey on Seawater Intrusion along Coastal Line in the Study Area

Table 6.2.1 Number of Preparatory Survey Points for Seawater Intrusion Investigation

Block / Province	A	B	C	D	E	F	G	No. of Block	No. of Survey Point
Phu Yen	14	6	6	8	26	12	62	7	134
Khanh Hoa	16	34	44	20	12	-	-	5	126
Ninh Thuan	7	65	2	10	-	-	-	4	84
Binh Thuan	18	36	8	48	36	10	-	6	156
						Grand Total		**22**	**500**

(2) Survey Periods

The survey was conducted in August 2007: the dry season for Phu Yen, Khanh Hoa and Ninh Thuan province and the wet season for Binh Thuan province, and November to December 2007: the dry season for Binh Thuan and the wet season for the rest three provinces.

(3) Survey items and Procedure

The survey items were i) depth of well, ii) groundwater level, iii) groundwater temperature, iv) conductivity, v) salinity, vi) pH and coordinates of the well. The instrument used for the survey was portable water level meters, portable water quality testers and GPSs.

6.2.4 Survey Results

Affection degree of seawater intrusion was classified into three categories as below.

- Less than 250 mg/L: Satisfy TCVN 5942-1995 (Drinking Water Standard for whole Vietnam)
- 250 to 400 mg/L: Satisfy TCVN 5943-1995（Drinking Water Standard for Coastal area）
- Over 400 mg/L: Dissatisfy Drinking Water Standards

Since chloride ion more than 200mg/l is an indication of seawater intrusion in general, above-mentioned category also means relative severity of it. For the purpose of the analysis, it is necessary to convert EC to chloride by the relation ship between them. Figure 6.2.3 shows it using the results of the water quality survey of existing water sources. Chloride ion concentrations of 500 points in the study area were calculated by the correlation equation in Figure 6.2.3. Figure 6.2.4 and 5 illustrate the affection of seawater intrusion in 2007.

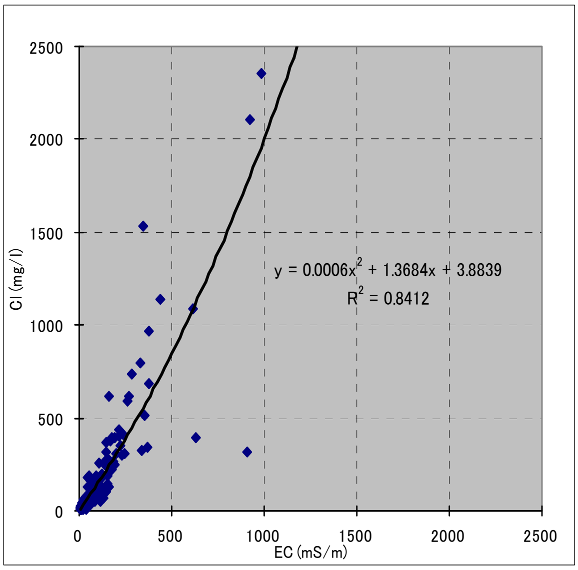


Figure 6.2.3 Relationship between Chloride and Electric Conductivity in the Study Area

Although a slight seasonal change in terms of salinity was detected between salinity in both seasons; lower salinity point increased and high salinity point deceased in the dry season as shown in Figure 6.2.4, it is not clear in the concentration distribution maps of chloride as shown in Figure 6.2.5 and Figure 6.2.6. Regional characteristics on seawater intrusion are described below.

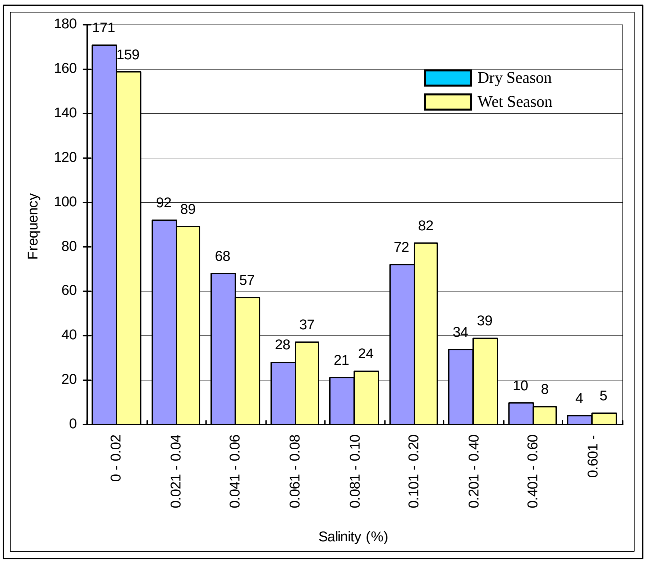


Figure 6.2.4 Salinity Distribution in both Seasons (Frequency: no of survey point)

(1) Phu Yen Province

Affection of seawater intrusion is found within seven km from shoreline of Song Cau and Tuy district. P-4 (An My) belongs to this area. Although the affected wells are found locally in Da Rang river delta which extends to Phu Hoa and Tuy Hoa district, almost whole area of the delta contains non saline groundwater because of enough recharge from Da Rang River.

(2) Khanh Hoa Province

Affection of seawater intrusion is found considerably in Tan Lam River basin and CAI river basin. Contaminated wells are found up to 18 to 27 km landward. Main reason for this is poor recharge condition caused by small-scaled catchment. Coastal zone of Cam Ranh district is generally affected by seawater intrusion. K-3 (Cam Hai Tay) belongs to this zone.

(3) Ninh Thuan Province

Almost whole coastal zone where is lower then 20 A.S.L.m is affected by seawater intrusion. Especially, such affected area extends up to approximately 22 km in Dinh River basin. All target communes; N-1 to N-6 belongs to this area. Main reason for this is poor recharge condition much severe than Khanh Hoa is caused by little precipitation.

(4) Binh Thuan Province

Although affected areas by seawater intrusion are found in lowland of Luy river basin in the eastern part of Binh Thuan province, and Tre river basin in the central part of the province where Phan Thiet is located, it is not so much than Ninh Thuan province. Only B-1 (Muong Man) is located near the affected area.

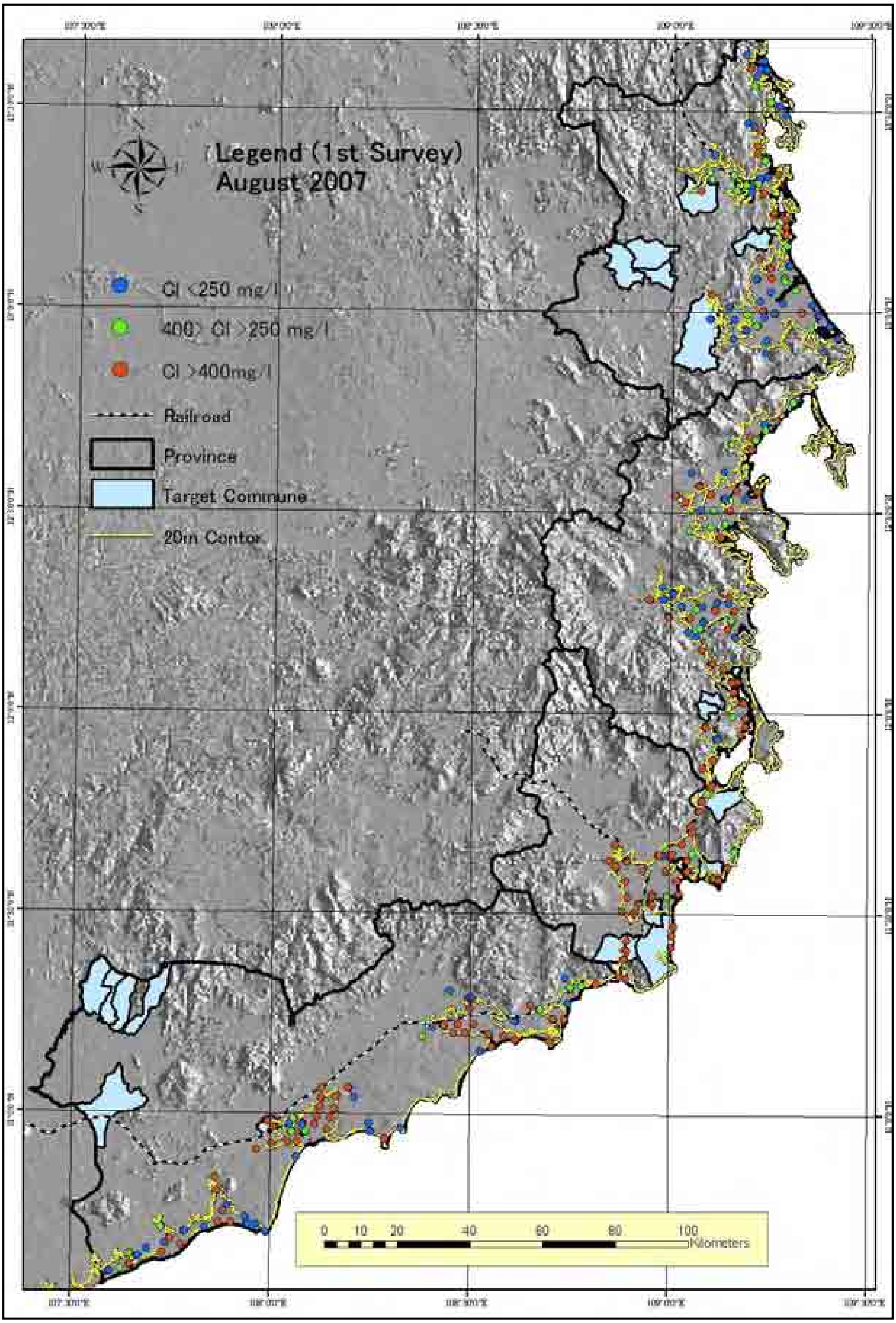


Figure 6.2.5 Results of Seawater Intrusion Survey in August 2007

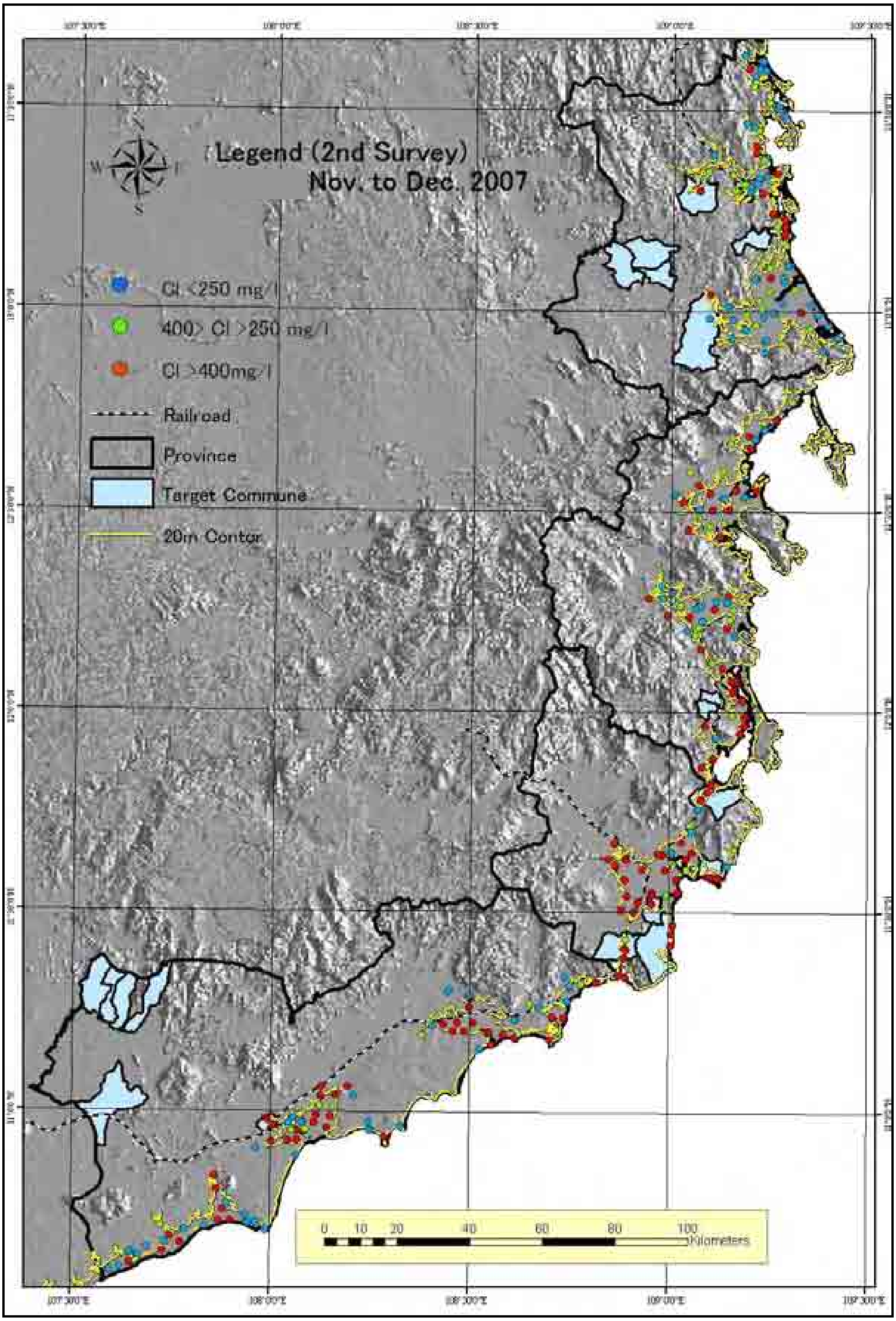


Figure 6.2.6 Results of Seawater Intrusion Survey in November to December 2007

6.2.5 Detailed Seawater Intrusion Survey

Detailed seawater intrusion survey was conducted in the selected nine communes: P4, K3, N1, N2, N3, N4, N5, N6 and B1, where seemed to be affected by seawater intrusion based on the preparatory survey.

(1) Survey Point

Twenty wells: mainly dugwells, in each commune were selected for this survey in view of the distance between wells and the coastline as shown in Figure 6.2.8 to Figure 6.2.14.

(2) Survey Period

The survey was conducted full day during the spring tide on 18th to 19th February 2008 and the measurements were done every hour.

(3) Survey Items

This survey consists of four sub survey items as follows.

1) Groundwater level

Measurement for monitoring wells near the coastline was carried out with convex in case of shallow level or with portable water level gauges in case of deep level. A height from the ground to the reference point for each monitoring well was measured precisely.

2) Water Quality

Water quality items were water temperature, conductivity, salinity and pH. Since the number of portable water quality testers was limited, the measurement carried out at 10 monitoring wells in each selected commune.

3) Tide Level

The Marine Hydrometeorological Center has been observing tide level since 1963. Three observation points locate in or near the study area as shown in Figure 6.2.7. The tide level data of them can be referred from "Tidal Tables in 2008 Vol.2" by National Hydrometeorological Survey Center.

4) Geodetic Survey

Ground heights and well heights (the reference points) were measured for the relation between salinity intrusion and groundwater.

Figure 6.2.7 Location of Related Tide Observation Station

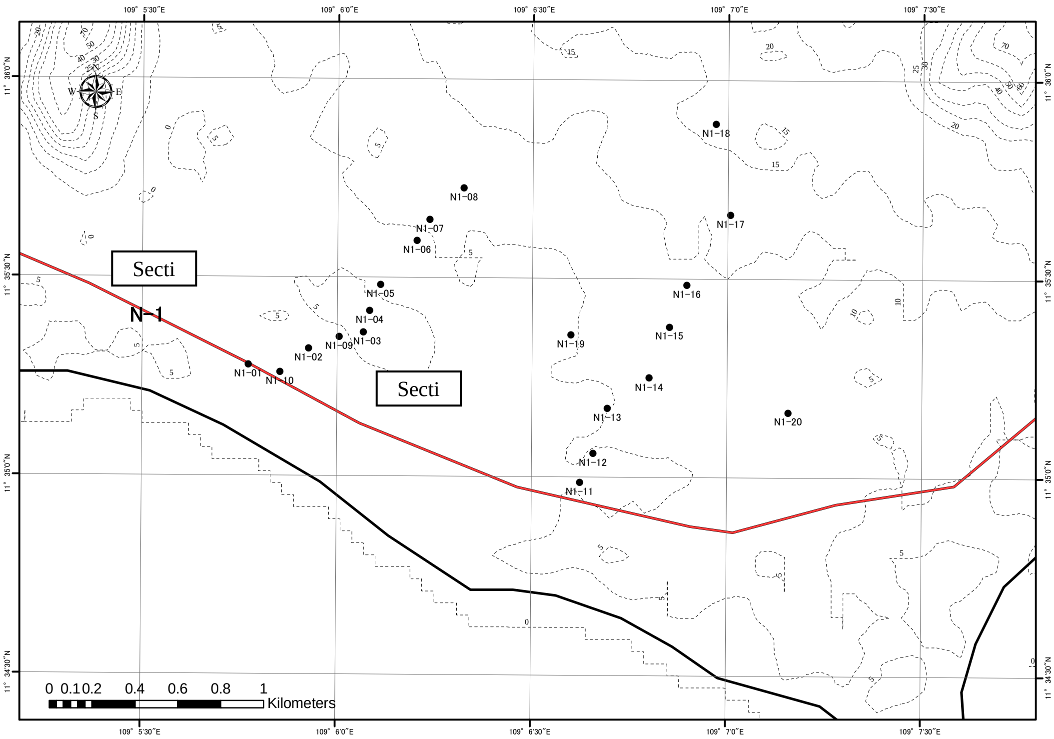


Figure 6.2.8 Location of Detailed Seawater Intrusion Survey in Nhon Hai (N-1)

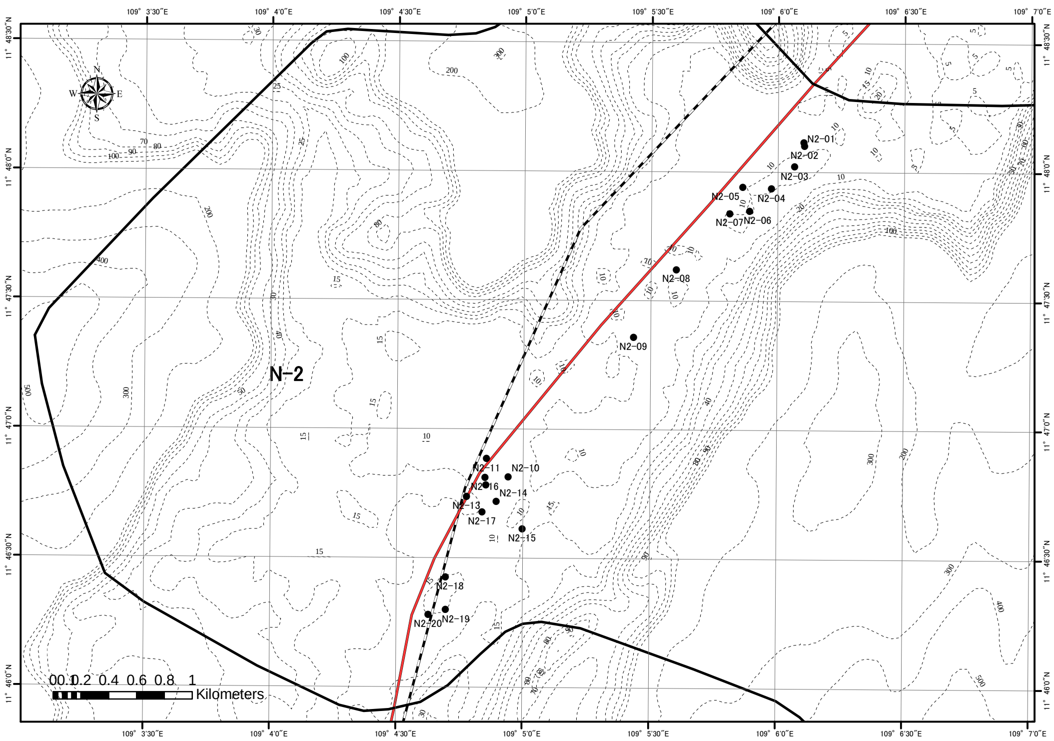


Figure 6.2.9 Location of Detailed Seawater Intrusion Survey in Cong Hai (N-2)

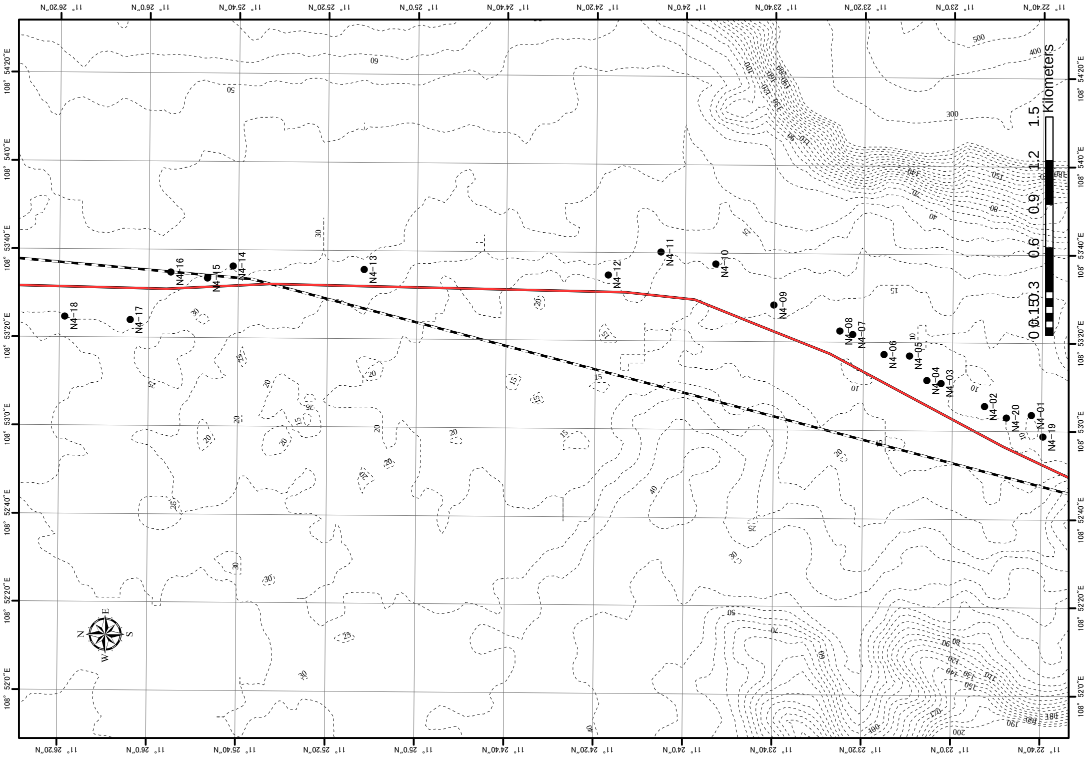


Figure 6.2.10 Location of Detailed Seawater Intrusion Survey in Phuoc Minh (N-4)

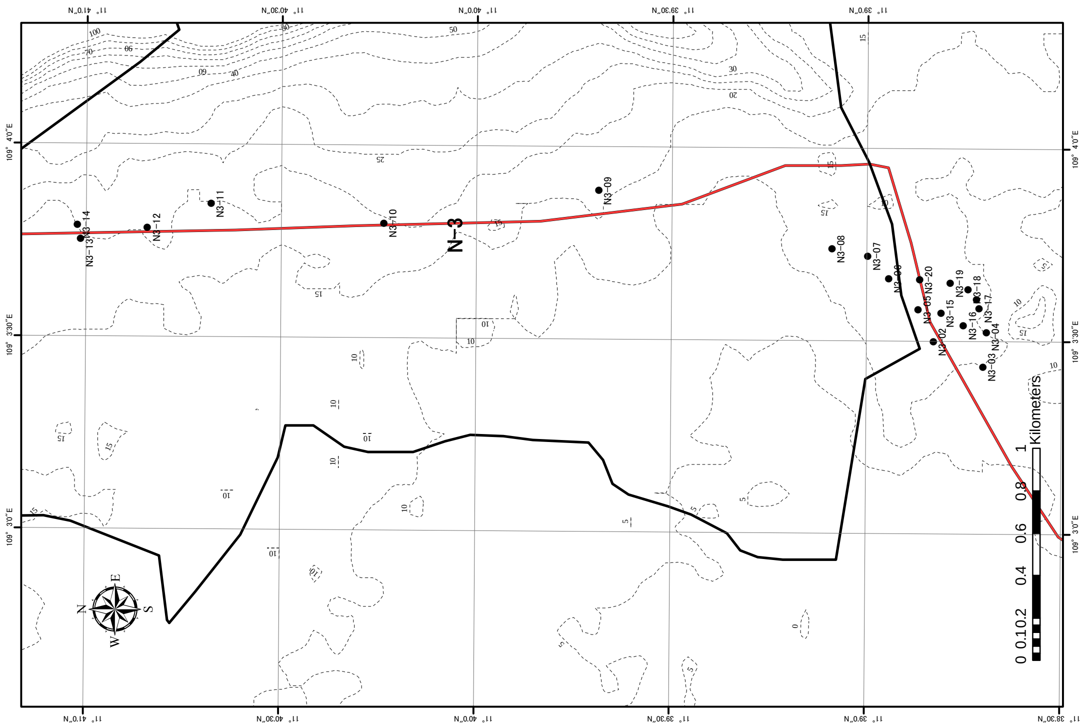


Figure 6.2.11 Location of Detailed Seawater Intrusion Survey in Bac Son (N-3)

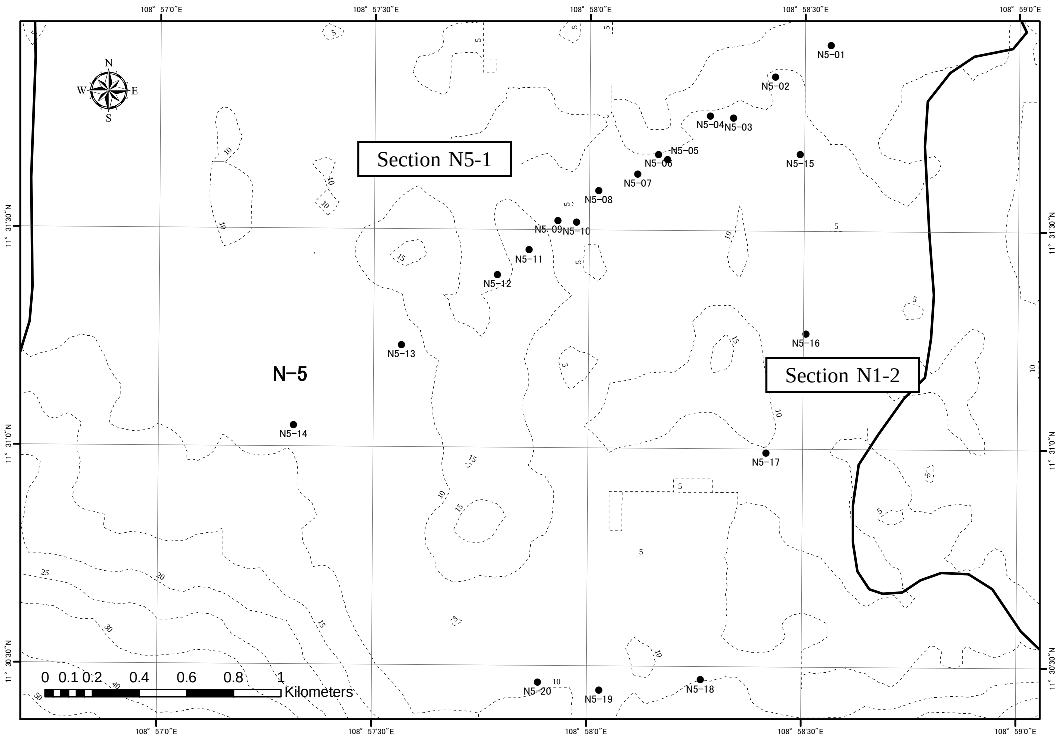


Figure 6.2.12 Location of Detailed Seawater Intrusion Survey in Phuoc Hai (N-5)

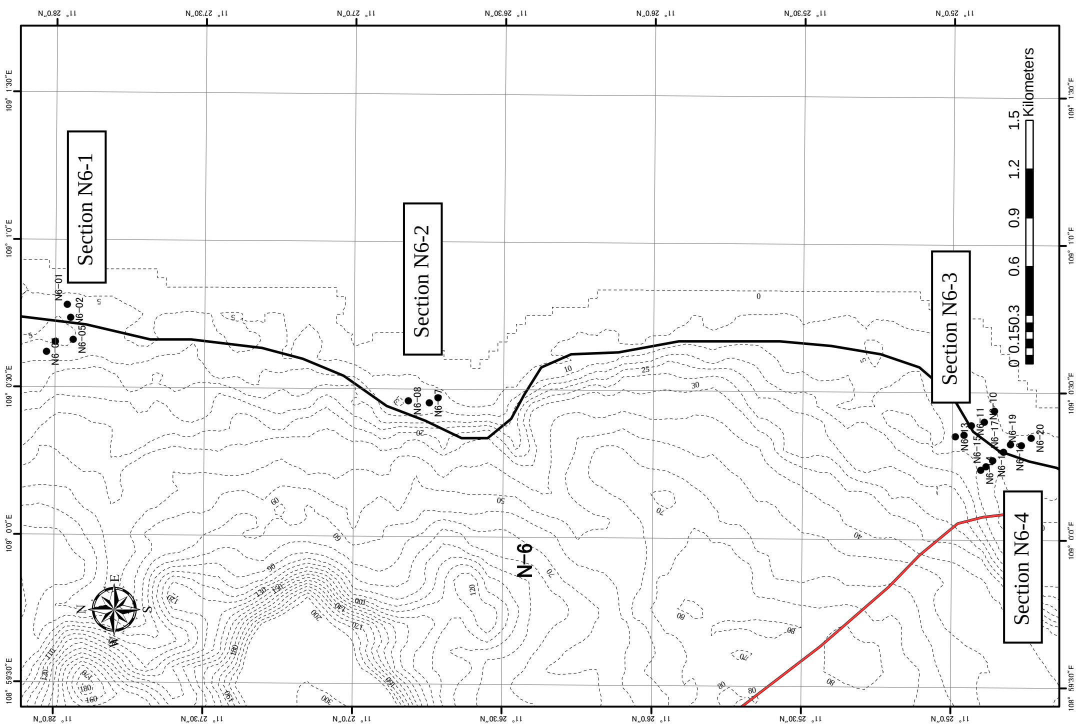


Figure 6.2.13 Location of Detailed Seawater Intrusion Survey in Phoc Dinh (N-6)

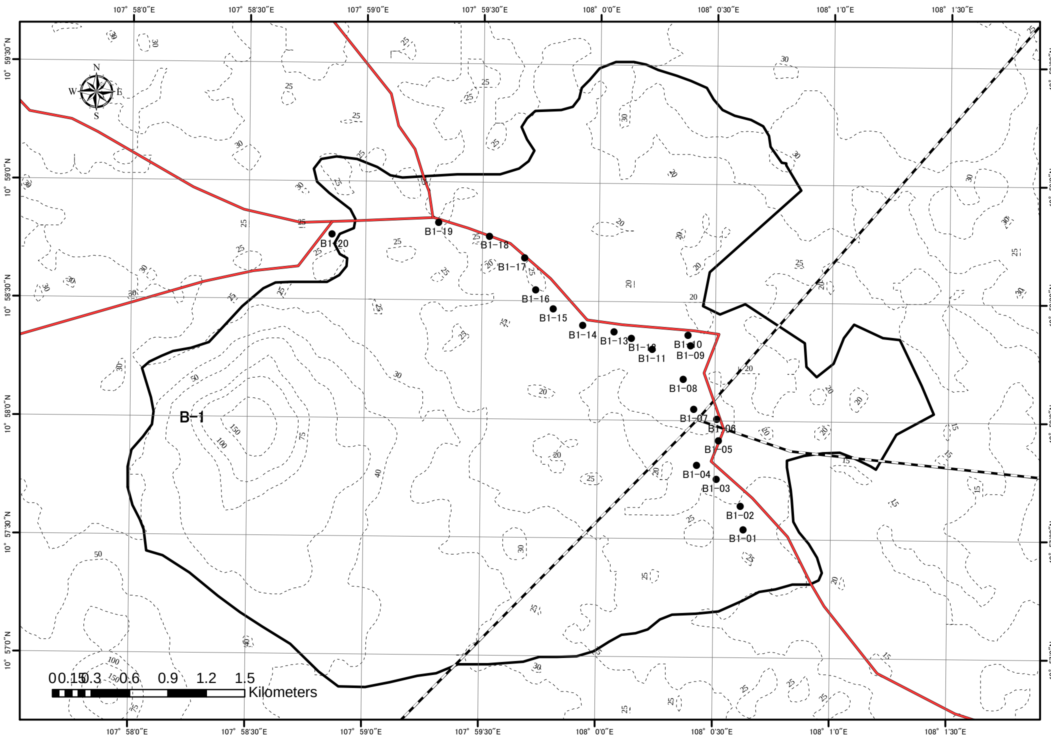


Figure 6.2.14 Location of Detailed Seawater Intrusion Survey in Muong Man (B-1)

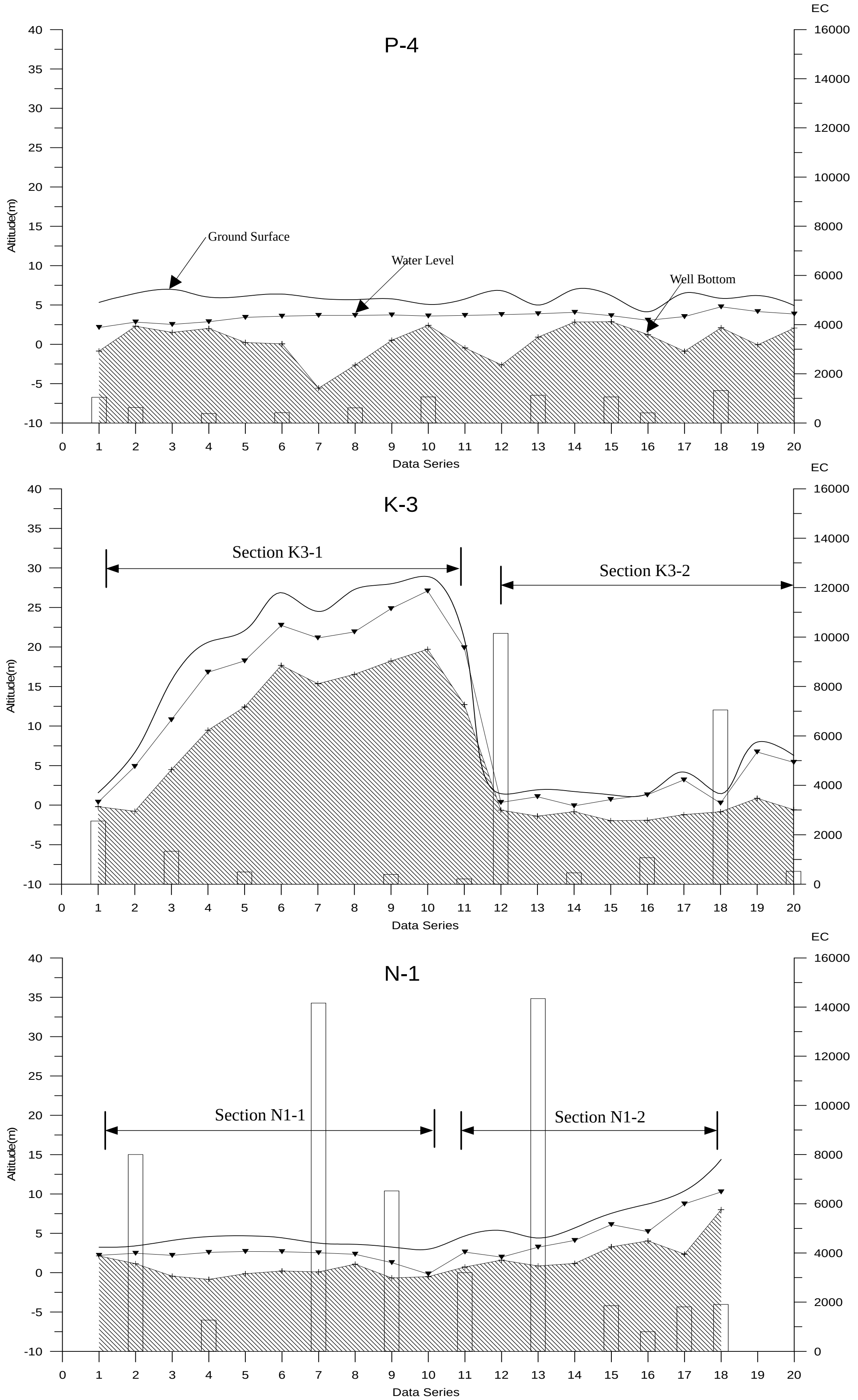


Figure 6.2.15 Relationship among Ground Level, Water Level, Well Depth and EC (1)

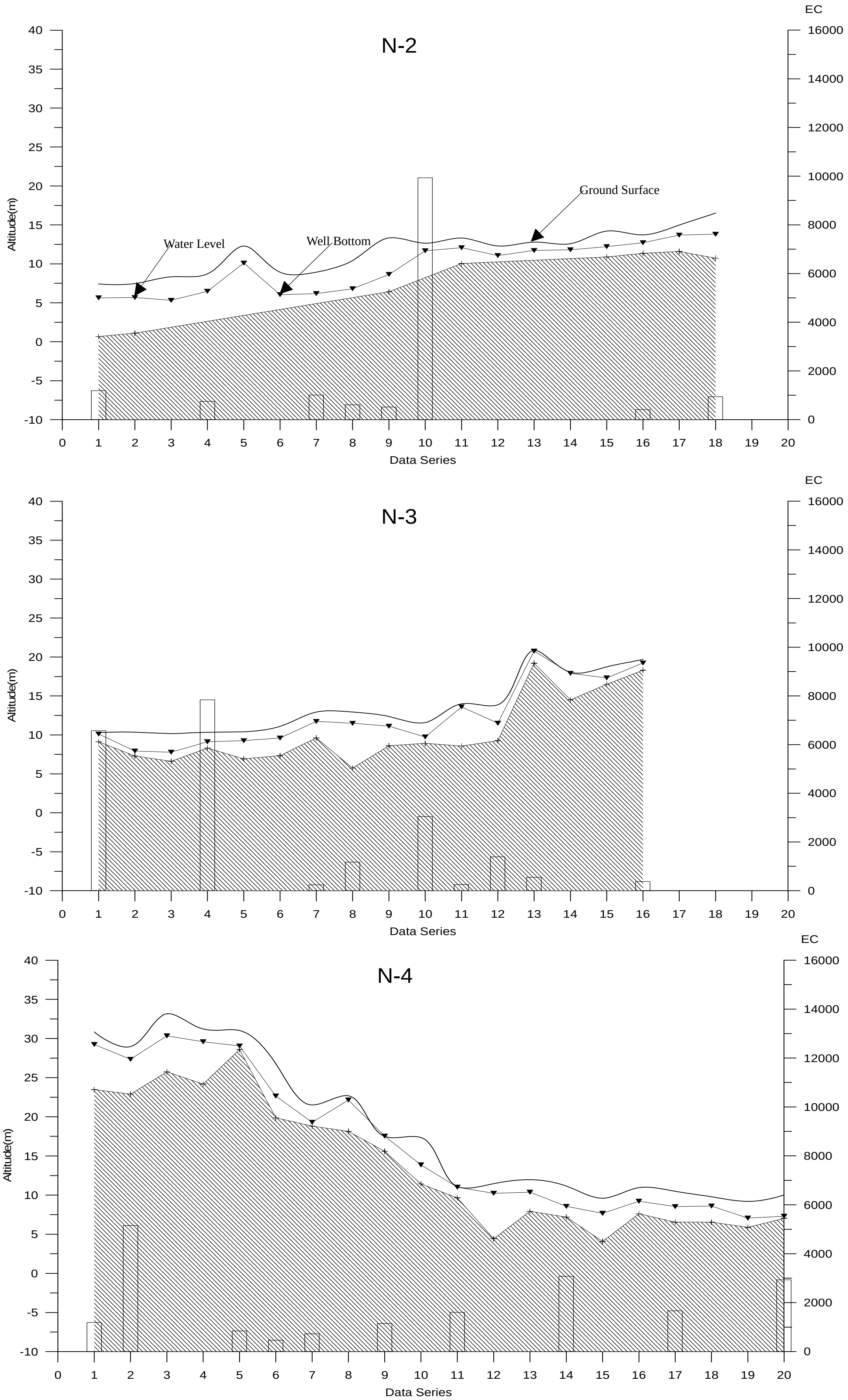


Figure 6.2.16 Relationship among Ground Level, Water Level, Well Depth and EC (2)

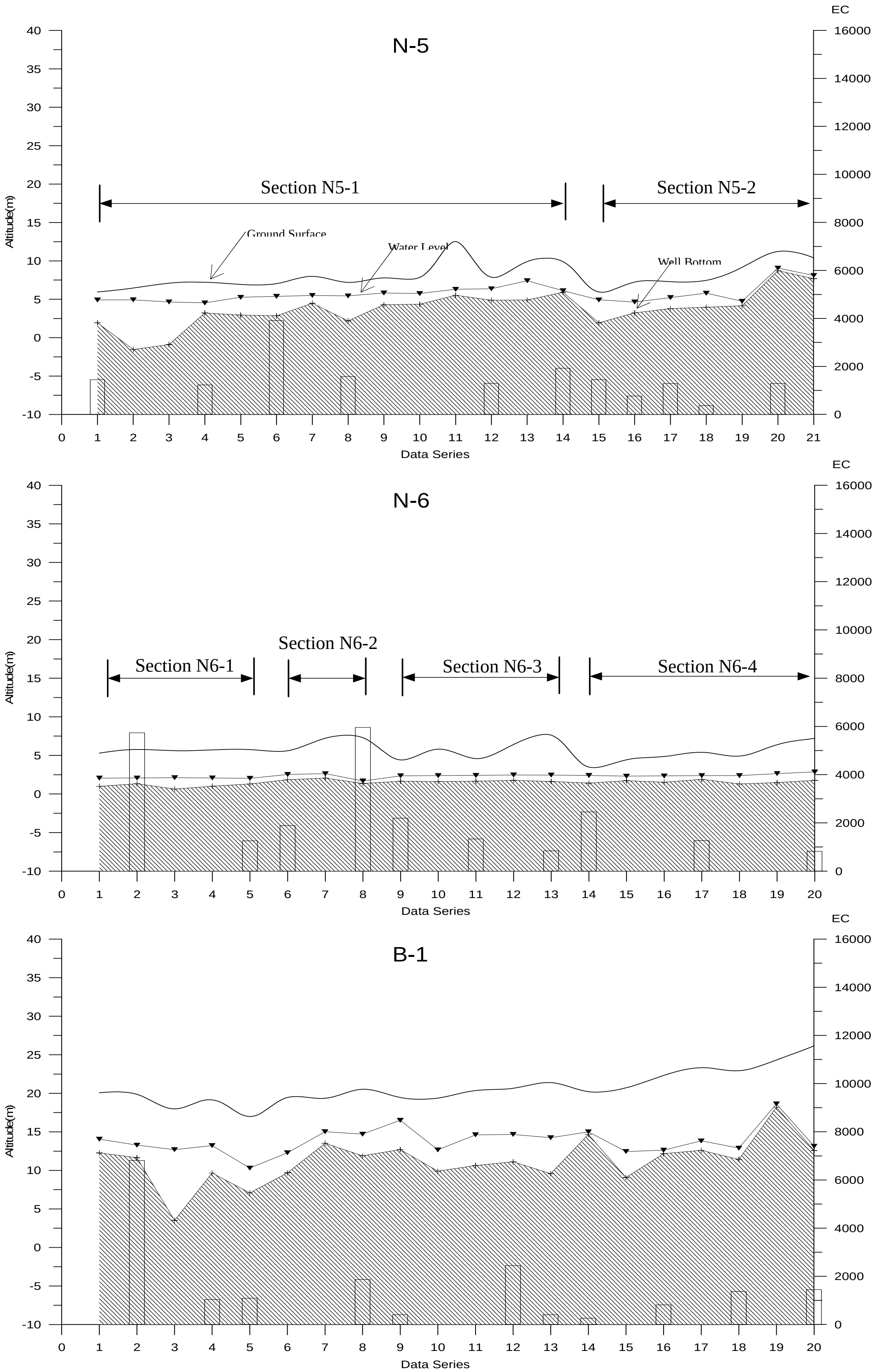


Figure 6.2.17 Relationship among Ground Level, Water Level, Well Depth and EC

(4) Survey Results

Figure 6.2.15 to Figure 6.2.17 present cross-sections of the selected nine communes. The figure consists of ground surface, average groundwater level of dugwells, bottom elevation of dugwells and electric conductivity by bar graph. Electric conductivity (EC), 2,500μS/cm is nearly equivalent to chloride 400mg/l. Therefore, there is a possibility that groundwater is affected by seawater intrusion in case it has higher EC value than 2,500μS/cm.

1) P-4

Cross-section is running form the south to the north along the shoreline of P-4 commune. Elevation of ground surface is about five meter above seawater level (A.S.L) and groundwater level is 2.5 to 4.0 m A.S.L. Since EC values of all dugwells are low, the impact of seawater intrusion seems to be slight.

2) K-3

According to the cross-section of inland side, there is no affection of seawater intrusion at all. However, seaside cross-section reveals some dugwells are affected by seawater intrusion. Elevation of their well bottoms is lower than 0m A.S.L and delicate balance between fresh water and seawater makes much difference of EC value.

3) N-1

Two cross-sections running shoreline to inland are prepared. They present prominent impact in the lowland area due to seawater intrusion.

4) N-2

Cross-section is located along a valley of hinterland. Bottom level of dugwells is 0m A.S.L to 8m A.S.L. Most of all dugwells are not affected by seawater intrusion based on EC values except No.10 dugwell, which has an extremely high value. According to its elevations of surface or well bottom and EC value of neighboring dugwells, saline water of No.10 is not caused by sweater intrusion but other sources.

5) N-3

Lowland of N-3 is affected by seawater intrusion.

6) N-4

Lowland of N-4 is affected considerably. Although No.2 dugwell, which is located at 30m elevation, records approximately EC 6,000mg/l, it is not caused by seawater intrusion.

7) N-5

Only No.6 dugwell shows affection of water salination. However, EC value of this commune generally is low and the affection of seawater intrusion is slight.

8) N-6

Some dugwells near shoreline have high EC values caused by seawater intrusion.

9) B-1

No.2 dugwell in the eastmost of B-1 commune seems to be affected by seawater intrusion but there is no water salination in the eastern side of this commune, where the ground surface is gradually coming upward.