CHAPTER 3 Considerations on Well Water Quality

3.1 Characteristics of Water Quality in the Bogotá Plain

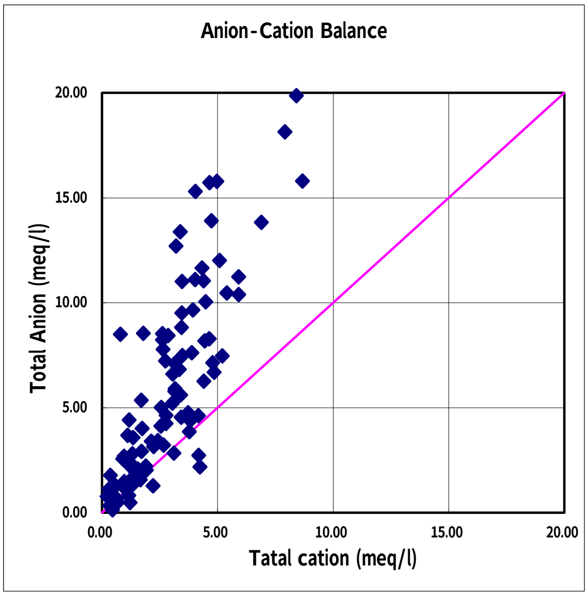
Ammonium-nitrogen, nitrite-nitrogen, and nitrate-nitrogen are generically called nitrogen compounds. Nitrogen compounds are used as indexes for contaminated water full of organic matter. This is because organic nitrogen contained in protein, amino acids, urea, *etc*., when put into water, dissolves into ammonium-nitrogen, which becomes nitrite-nitrogen when oxidized, and then becomes nitrate-nitrogen when further oxidized. The presence of many ammonium ions indicates a deoxidization state while the presence of many nitrate ions indicates an oxidization state. In the entire Bogotá Plain, ammonia more than the standard value was detected but nitrate-nitrogen and nitrite-nitrogen seldom exceeded the standard value. This indicates that the entire Bogotá Plain is in a deoxidization state. This tendency is also apparent from the fact that, among the sulfur compounds, little sulfates were found while a high concentration of hydrogen sulfide was detected in the entire Bogotá Plain. Although iron and manganese were also detected to exceed the standard values in the entire Bogotá Plain, this is assumed to be because, due to a deoxidization state of the groundwater, iron and manganese in the strata had dissolved as iron and manganese ions.

3.2 Hydrogeological Characteristics

(1) Major Ion Components

Figure-3.1 shows, from the result of Phase 1 test, the ion balance between major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, and NH_4^+) and anions (NO_3^-, Cl^-, SO_4^{2-}, HCO_3^-, and CO_3^{2-}) that make up the groundwater. (Total Fe was assumed in the test but divalent iron [Fe^{2+}] was assumed in this analysis because, generally, the groundwater mainly contains divalent iron.) Since the ion balance between the total cations and total anions is ideally 1:1, the balance of major ions with high-concentration ions in the study area is supposed to approach 1:1 without limit. However, Figure-3.1 shows that the result is unbalanced on the whole (there are exceedingly more anions than cations).

Among the items that exceeded the standard values in all the study area, the sulfate (SO_4^{2-}) significantly exceeded the standard value for many of the wells only in Phase 1 and indicated a very much different value from the one in Phase 2. If the sulfate is removed from the major anions, the result is as shown in Figure-3.2, which indicates a much improved ion balance.



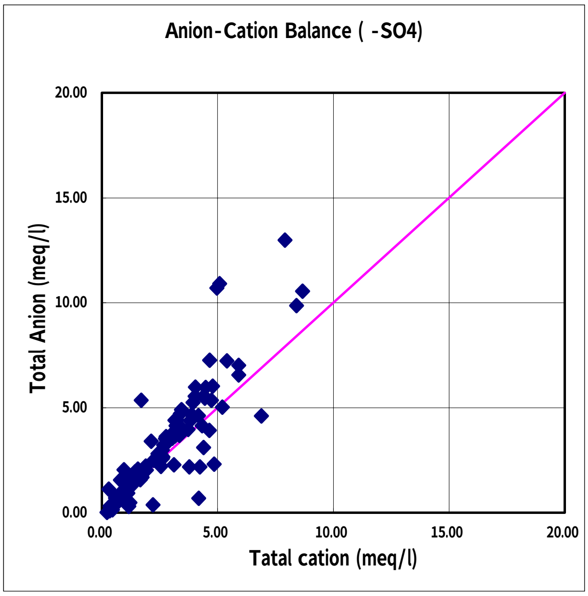


Figure-3.1 Ion balance between major cations and anions (Phase 1)

Figure-3.2 Ion balance excluding SO_4^{2-} (Phase 1)

The ion balance of the test result Phase 2 and 3 are shown in Figure-3.3 and Figure-3.4.

As is apparent from these graphs, Phase 1 test data has a bad ion balance compared with Phase 2 and 3 tests data even after the sulfate is removed. Since the analysis result of Phase 2 and 3 tests seem appropriate, the analysis result of Phase 1 test has a low degree of reliability.

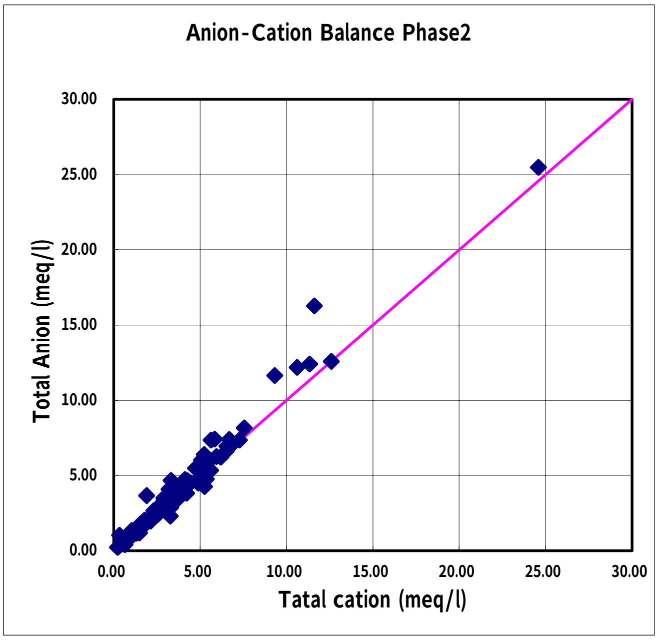


Figure-3.3 Ion balance between major cations and anions (Phase 2)

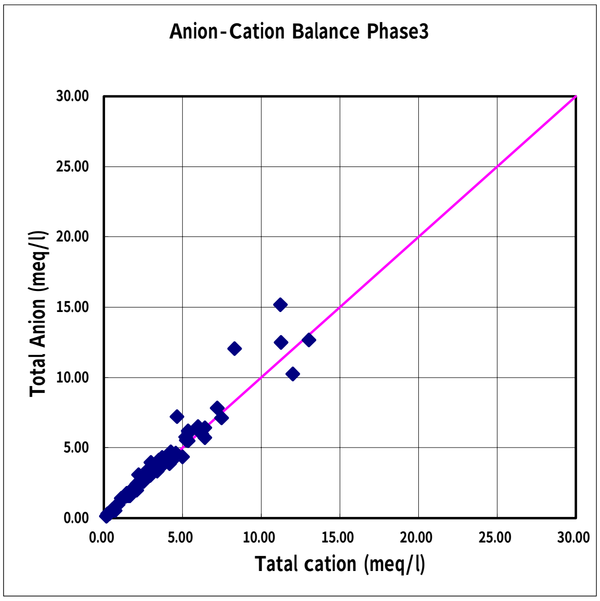


Figure-3.4 Ion balance between major cations and anions (Phase 3)

(2) Tri-linear Diagram

Concerning Phase 2 and 3 tests with a relatively high degree of reliability for the analysis result, a tri-linear diagram for major ion components (eight components; Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}, and CO_3^{2-}) were created by aquifers and shown in Figure-3.5(1) through Figure-3.5 (3). These diagrams indicate that, for grand water in the Quaternary aquifers, these ion components are dominated in the Na-HCO_3 type, which is generally found in deep-aquifer groundwater, and widely distributed in the Ca-HCO_3 type, which is generally found in shallow-aquifer groundwater. Furthermore, the ion components in the Na-Cl type, which is generally found in seawater and fossil water, and in the Ca-Cl type, which is generally found in volcanic stones, were also distributed. For groundwater in Cretaceous aquifers and Tertiary aquifers, the water quality composition did not vary much among different aquifers, and the characteristics of these ion components is not significant.

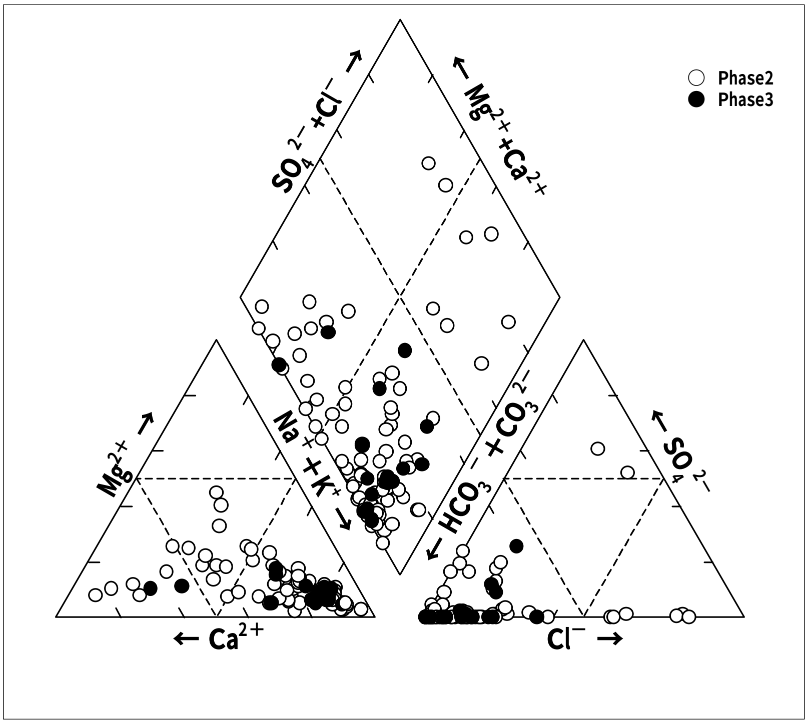


Figure-3.5 (1)   Tri-linear Diagram (Quaternary)

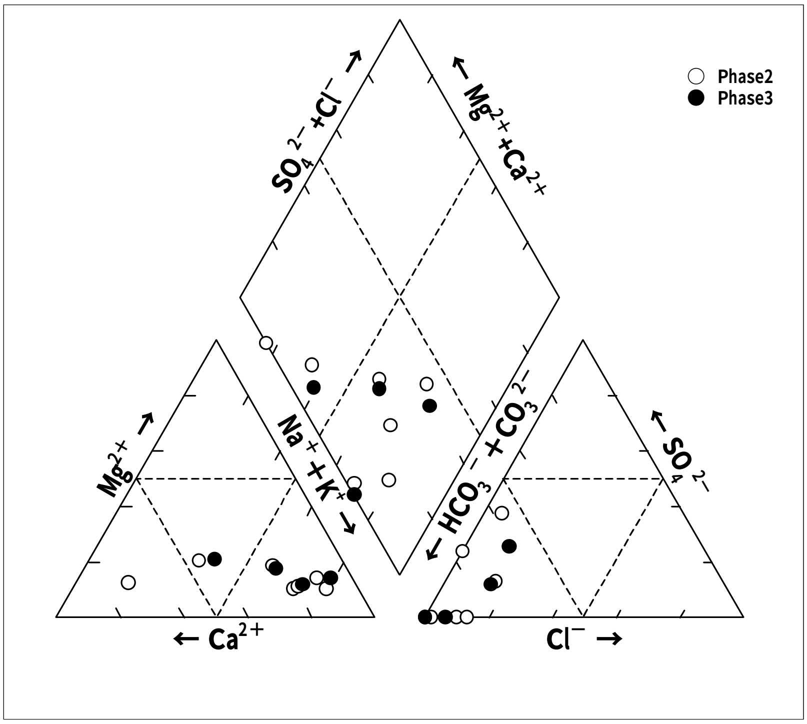


Figure-3.5 (2)   Tri-linear Diagram (Tertiary) (continute)

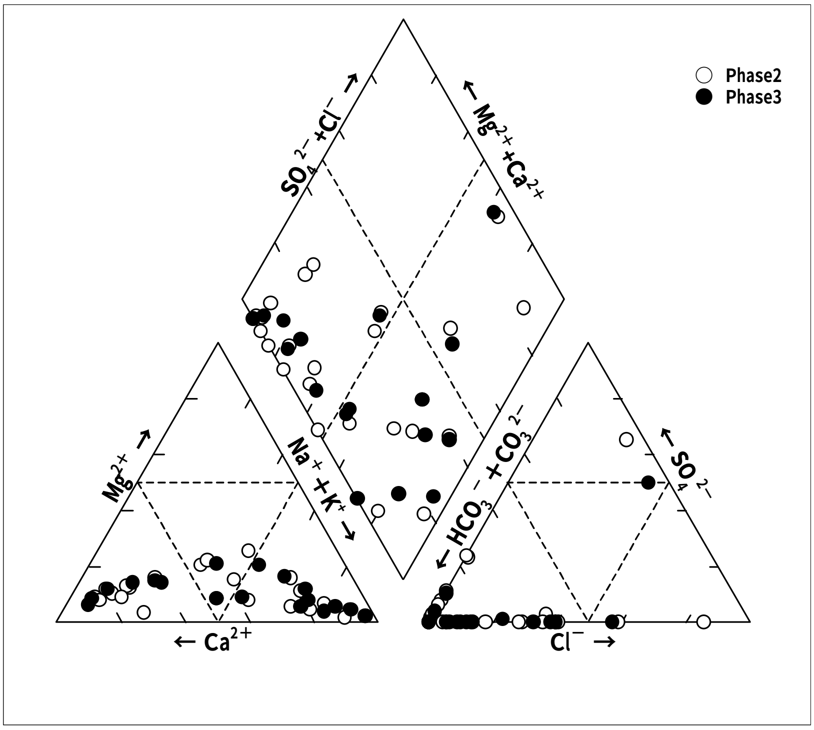


Figure-3.5 (3) Tri-linear Diagram (Cretaceous) (continue)

(3) Hexa Diagram

This hexa diagram for each aquifer is shown in Figure-3.6 (1) to Figure-3.6 (3).

In the hexa diagram of each topographic map, these 8 components were categorized statistically into 10 items through the cluster analysis on concentration, which are identified in different colors. (These components were classified not only in composition rate but also in concentration, for the cluster analysis). The characteristics of water quality of the main categories shown in Figure-3.7 indicate that Category 1 is Na-HCO_3 type water, Category 2 low-concentration water of the same type, and Categories 6 and 7 are high-concentration water of the same type, while Category 4 is Ca-HCO_3 type water. As observed generally, the groundwater changes from Ca-HCO_3 type to Na-HCO_3 type with the stagnating time underground. It is thus presumed that the water quality varies from Category 4 (relatively new Ca-HCO_3 type groundwater) → Category 1 (advanced Na-HCO_3 type groundwater) → Category 6 or 7 (groundwater with higher concentration of Na-HCO_3).

Through the observation of the water quality in the Quaternary aquifer (Figure-3.6 (1)), the north area and the fringe area of the basin shows Category 4 while the internal basin area shows Category 1 extensively and the central area of the basin Categories 6 and 7. These changes are attributed to the water quality of the groundwater flow from the fringe area to the central area of the basin. In the Cretaceous aquifer (Figure-3.6 (3)), the water quality of Category 4 is shown in the basin fringe area, while Category 6 is shown in the central area of the basin. This means that the groundwater flowing from the fringe area to the central area of the basin is also attributed to a change of the water quality. These analysis results supported the results of the groundwater flow analysis made separately.

In addition, it was observed that the wells in the mountainous area, belonging to the Quaternary aquifer, show the features of $Ca\text{-}HCO_3$ type water in the Cretaceous aquifer. It can be presumed that the wells with the thin coverage of the Quaternary aquifer are affected by the Cretaceous aquifer. The wells in the Cretaceous aquifer that are distributed in the plain area show the $Na\text{-}HCO_3$-type features similar to the Quaternary aquifer. This means that these wells were created as the multi-screen structure to take in water from multiple aquifers. Therefore, the water in the Quaternary aquifer may have penetrated into these wells.

Hexa diagrams on Phase 3 were made by the method same as that on Phase 2. The result of Phase 3 showed a roughly similar result of Phase 2. (See Figure-3.8)

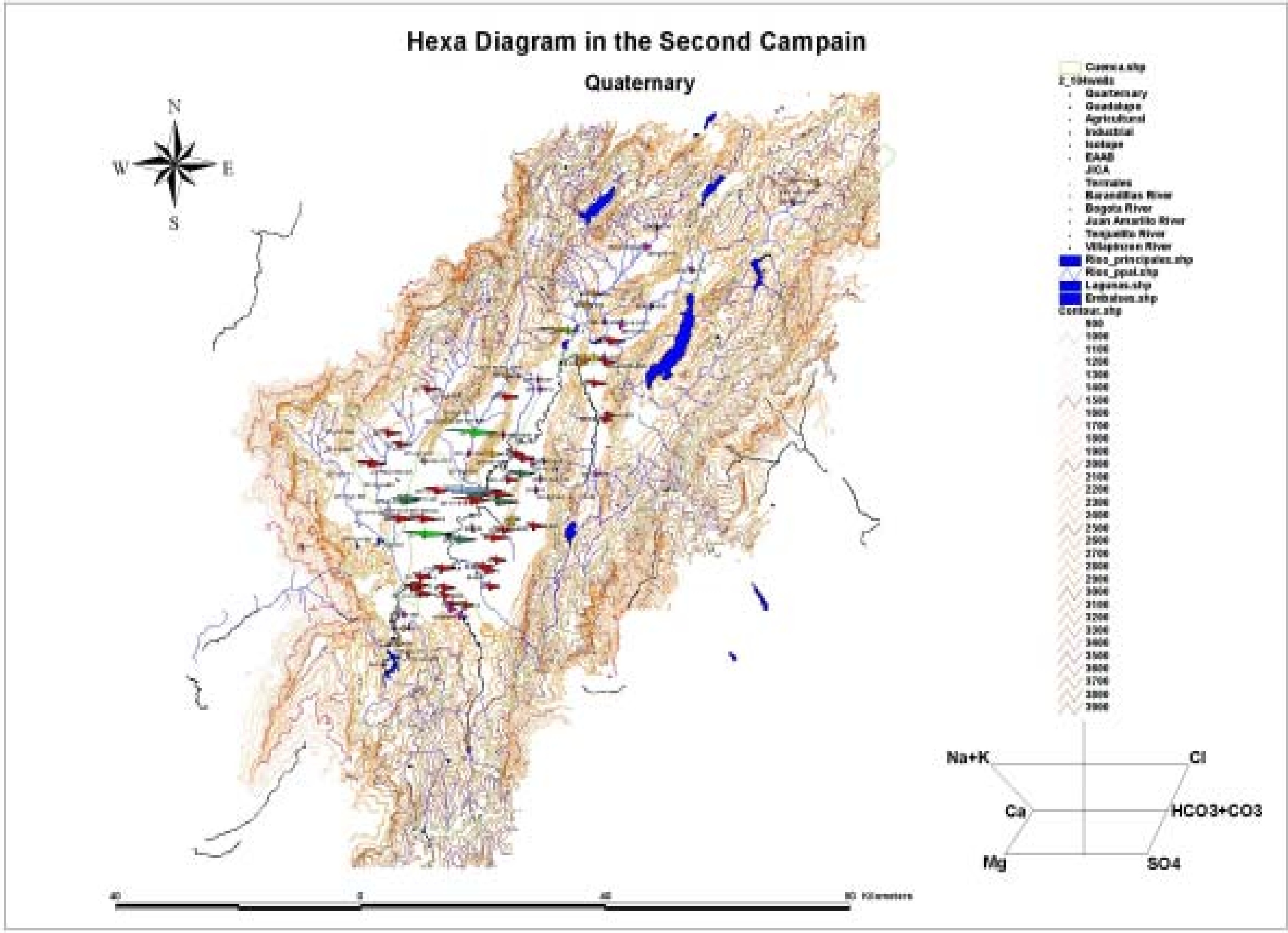


Figure-3.6 (1) Hexa Diagram of Quaternary Aquifer (Phase 2)

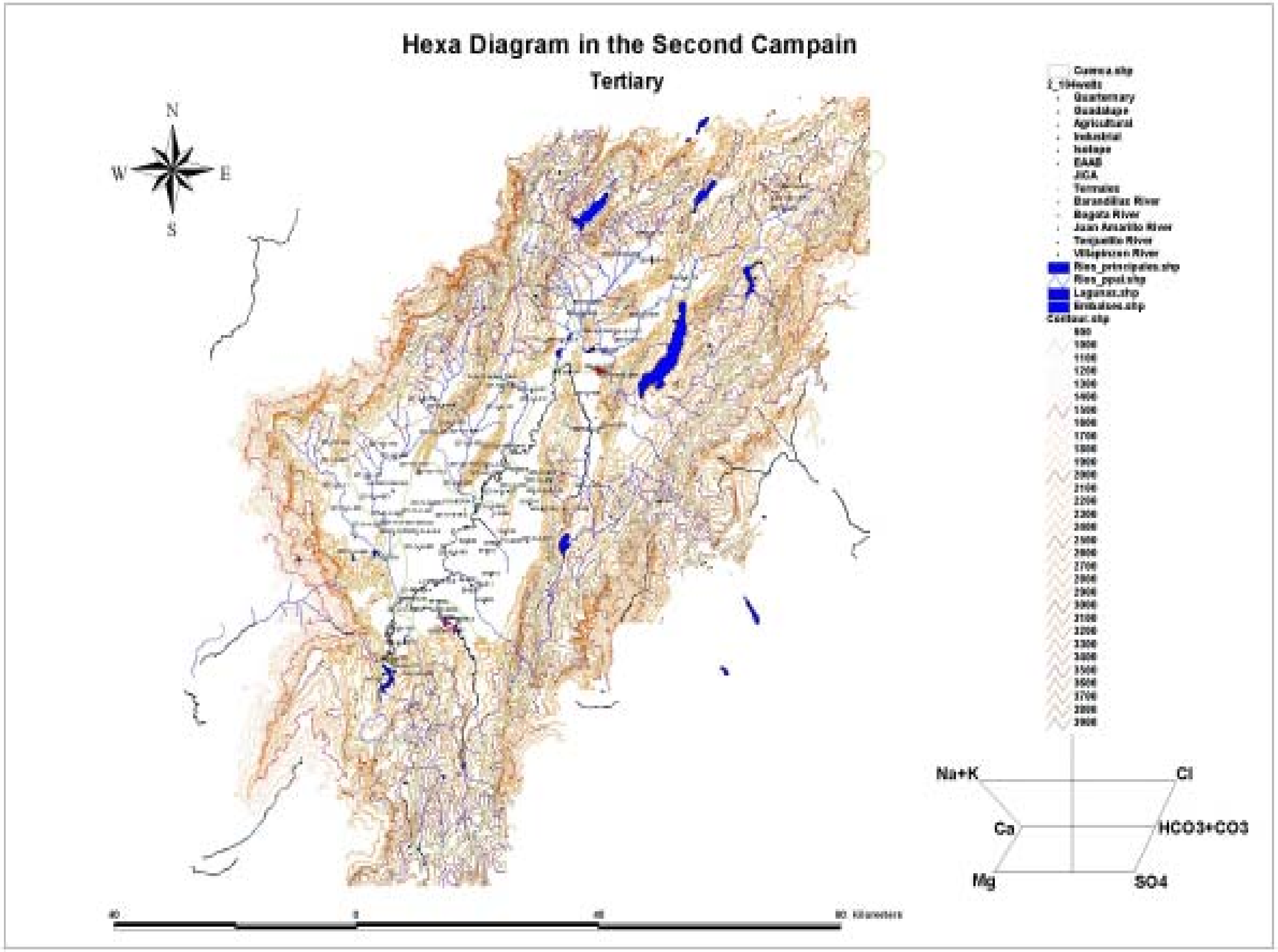


Figure-3.6 (2) Hexa Diagram of Tertiary Aquifer (Phase 2)

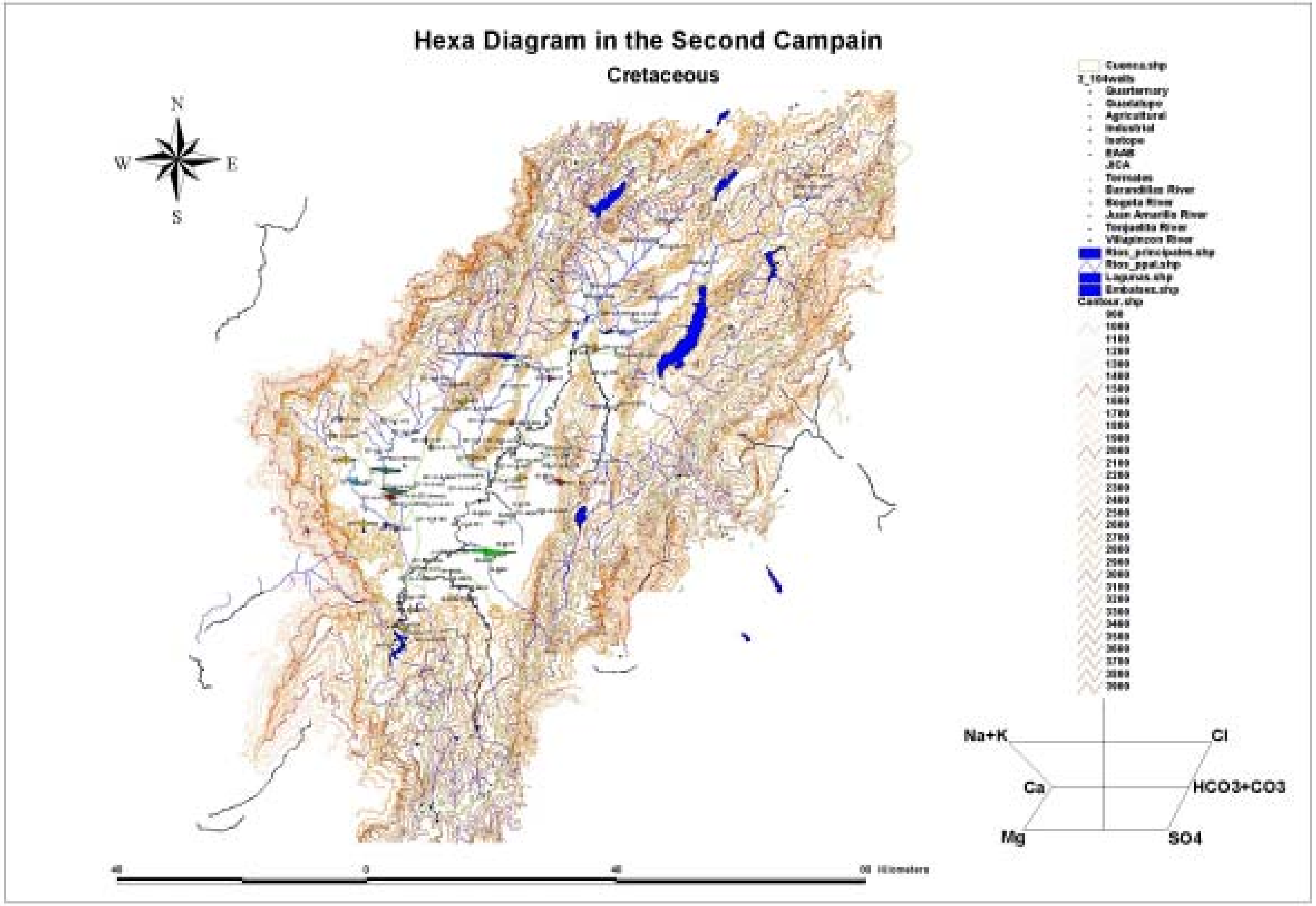


Figure-3.6 (3) Hexa Diagram of Cretaceous Aquifer (Phase 2)

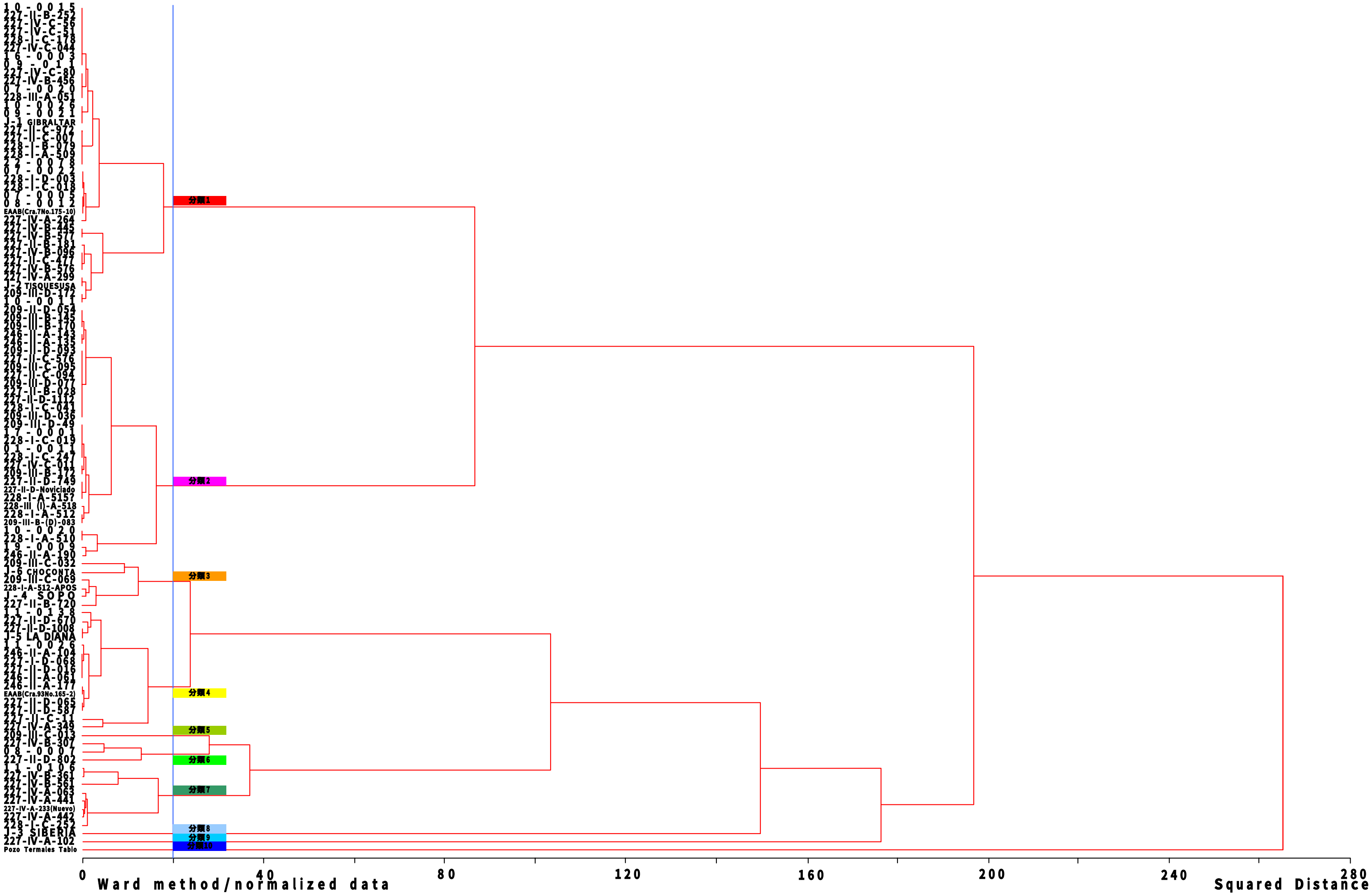


Figure-3.7 Cluster analysis of well water quality

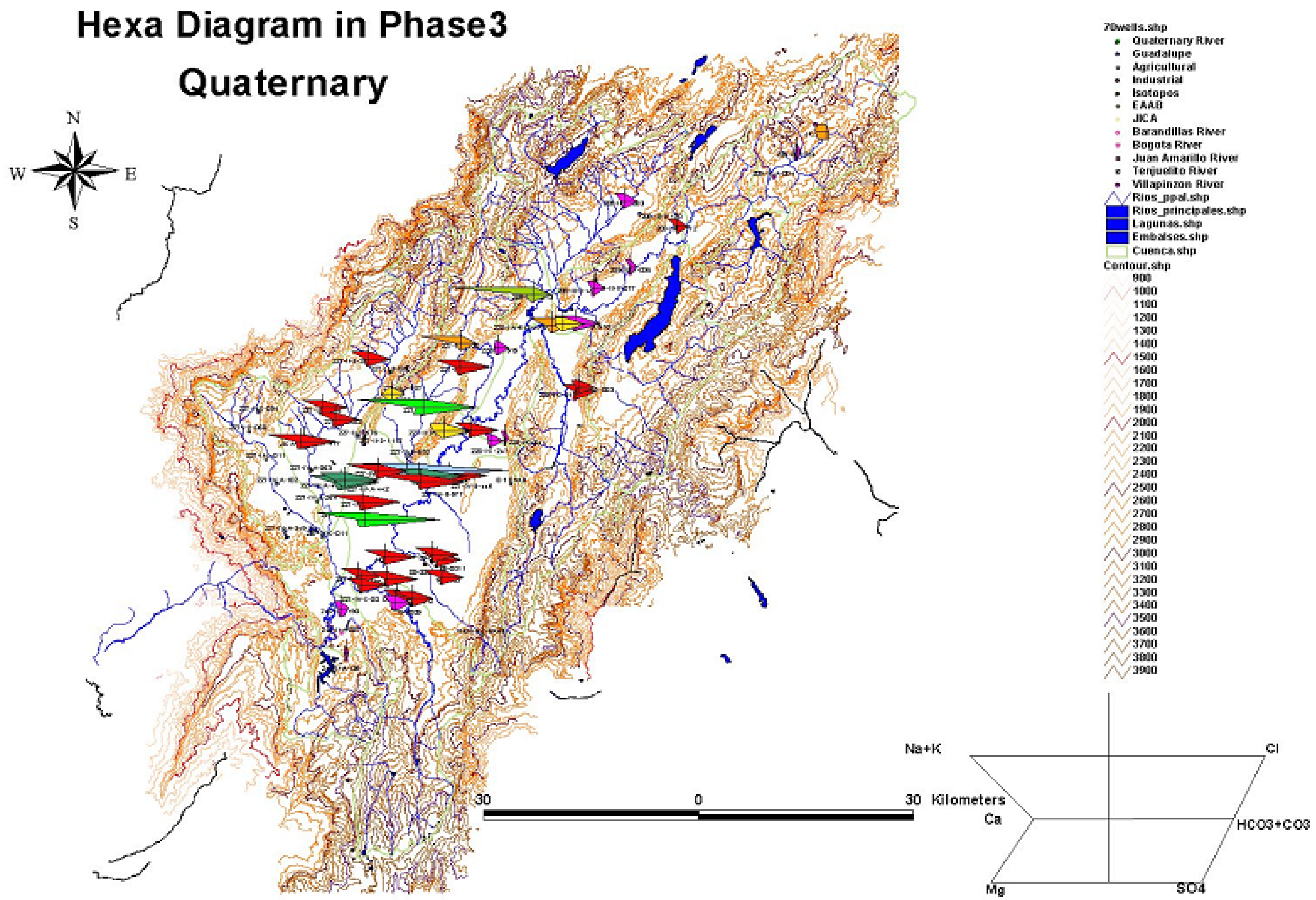


Figure-3.8 (1) Hexa Diagram of Quaternary Aquifer (Phase 3)

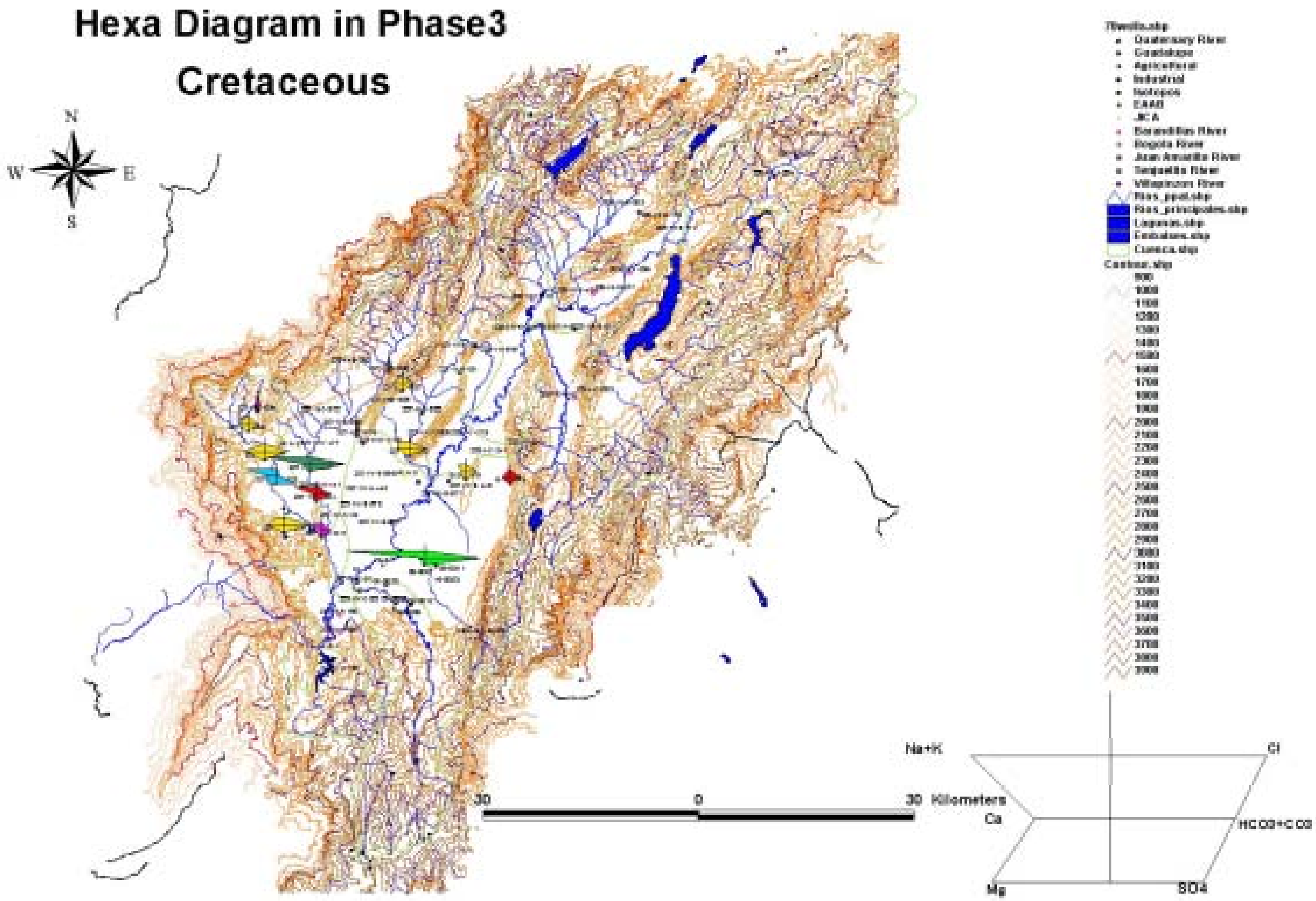


Figure-3.8 (2) Hexa Diagram of Cretaceous Aquifer (Phase 3)

3.3 Characteristics of river water quality and its relation to well water quality

In Phase 3, water quality test for superficial water of river were carried out on same items as underground water. According to the cluster analysis of those results, it has roughly divided into 4 clusters as shown in Figure-3.9

Figure-3.10 and 28-36Figure-3.11 show the Tri-linear Diagram and Hexa Diagram by using this results.

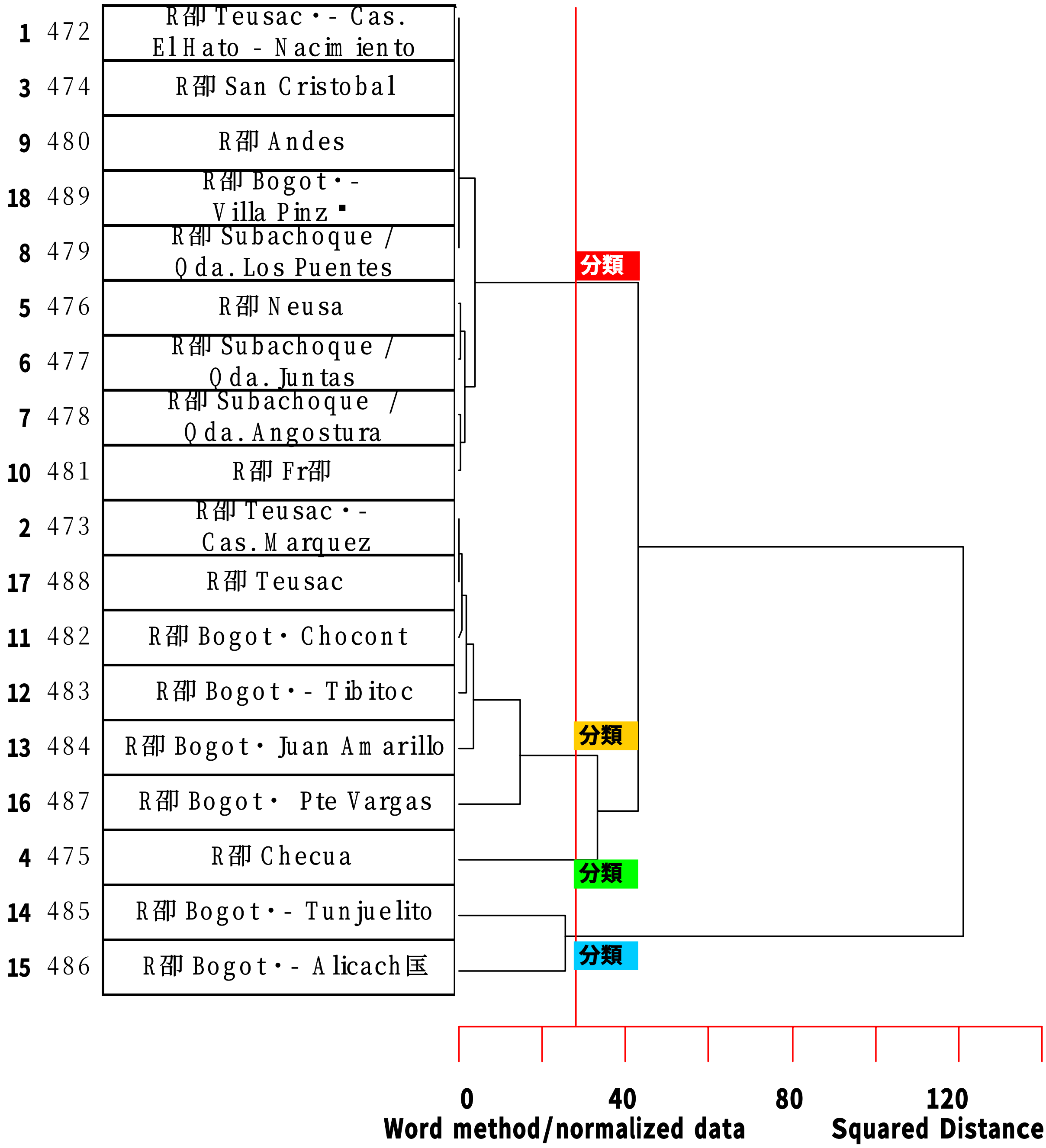


Figure-3.9 Cluster analysis of river water quality test data

(1) Tri-linear Diagram

Generally river water is categorized into Ca－HCO_3 type as shown in Figure-3.10. Therefore, well water most of which show Na－HCO_3 type are different from the type of river water. Normally, if groundwater remains long time, SO_4^{2-} reduced and HCO_3^- increases. At the same time, there are tendency to be $Ca^{2+} < Na^+$ and change from Ca－HCO_3 to Na－HCO_3. Accordingly, it is considered that the difference between the type of river water and that of groundwater is due to so long remaining time under the ground.

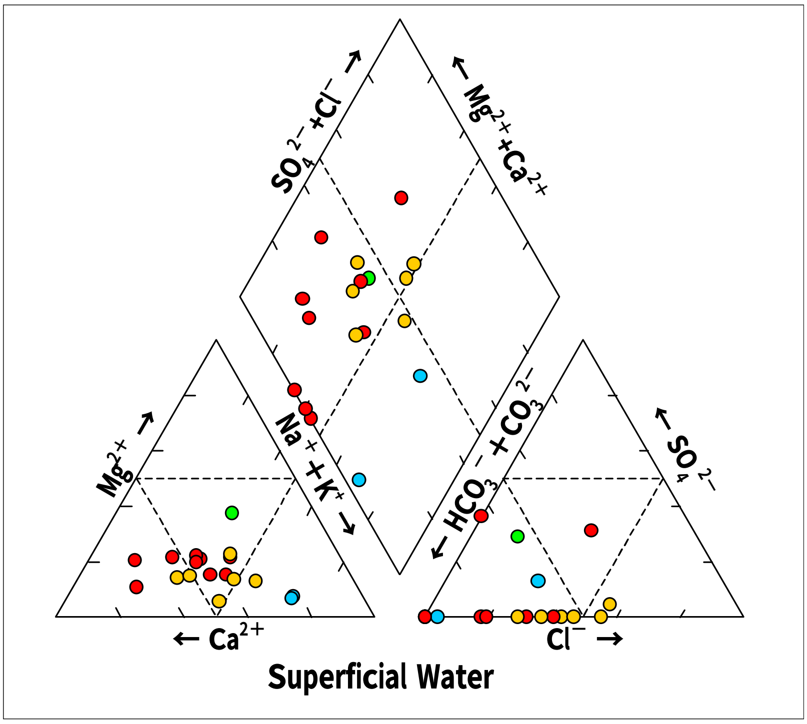
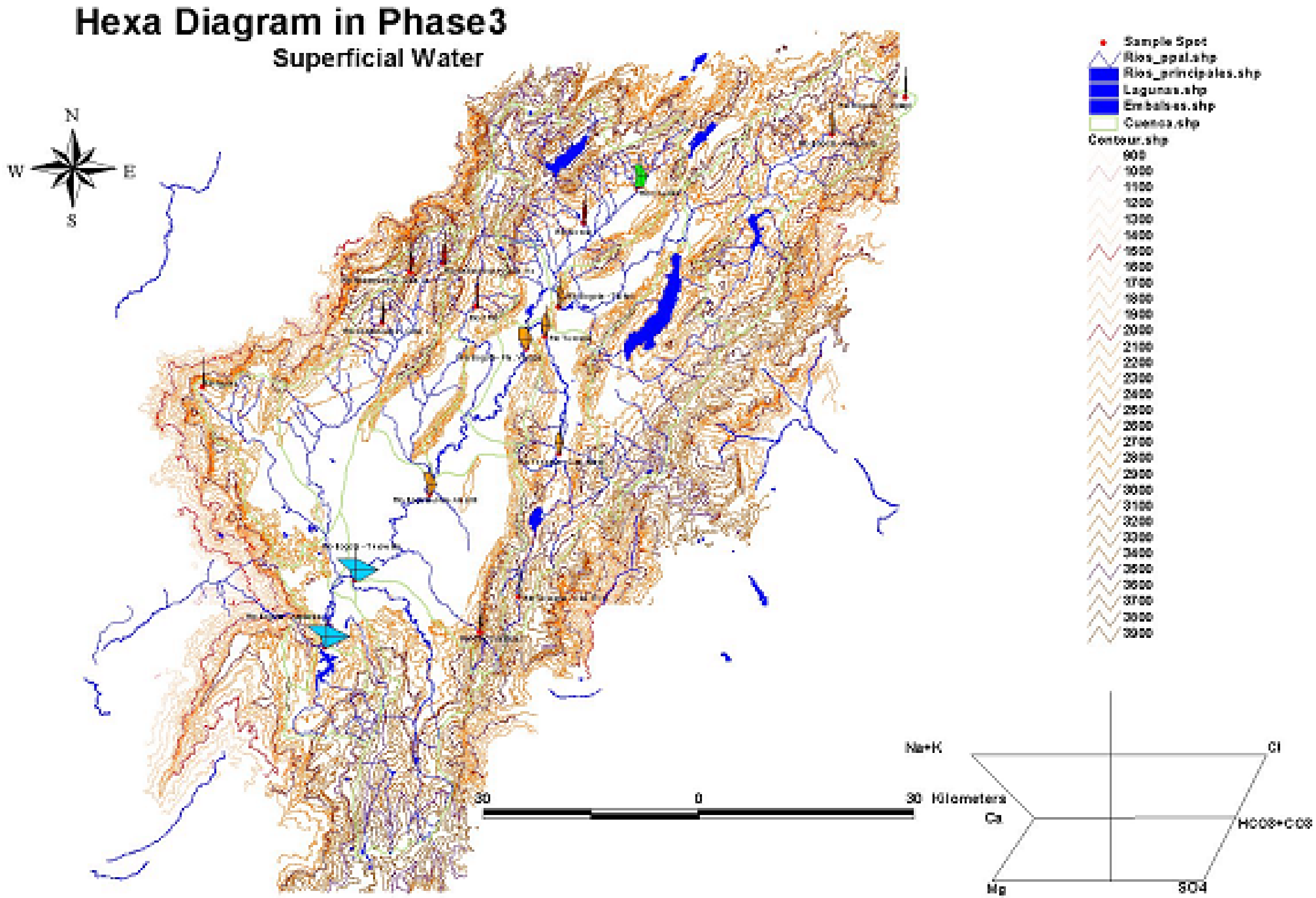


Figure-3.10 Tri-linear diagram (Superficial water of river)

(2) Hexa Diagram

It has been categorized into 4 clusters by the result of Cluster Analysis. According to geographic distribution of each cluster data, it is clearly identified that Cluster 1 is the water quality of mountainous area, Cluster 2 is the water quality of Bogotá river, Cluster 3 is the water quality of rock salt area, and Cluster 4 which was Na－HCO_3 type in tri-linear diagram is the water quality of the Bogotá city. (See 28-36Figure-3.11)



28-36Figure-3.11 Hexa Diagram of river water (Phase 3)

(3) Rating Scheme of Groundwater Quality

A large quality of water quality and environmental data was collected in the study. It is important for water users or consumers to clarify the quality of groundwater in individual basins if a basin has suitable groundwater quality for intended uses or not. However, since the parameters relating the water quality, are too many in species and differ from the national standard, it is not easy to appraise the water quality immediately. A proposed rating method is one of solution of the problem.

The rating procedure, that is applicable to the judgment of water quality in the basin, is illustrated in the following. The method is an empirical assessment methodology in nature, so that developing it requires a participation of several experts concerned deeply in the water quality. The method is applied in the areas of drinking and agricultural uses.

(4) Parameters to be evaluated and those standard criteria

Although the parameters using for the rating scheme are mainly selected from the national standard of raw waters, some extra items are also required for improving evaluation. It is necessary to discuss with local water quality experts to determine additional parameters. The following tables were prepared in prior to the workshop.

Table-3.1 Selected Parameters for the Raw Water of Drinking

Parameters used for evaluation	Water standard for the raw water prior to conventional water treatment (raw water 1)	Water standard for the raw water prior to chlorination (raw water 2)
NH_4－N	1.0	1.0
Ba	1.0	1.0
True Color Unit	75 unit	20 unit
NO_3－N	10	10
ESCHERIC IHA		
COLIFORME		
H_2S (added)	0.05 (WHO)	0.05
Fe (added)	0.3 (Japan)	0.3
Mn (added)	0.05 (Japan)	0.05
COD		
BOD		

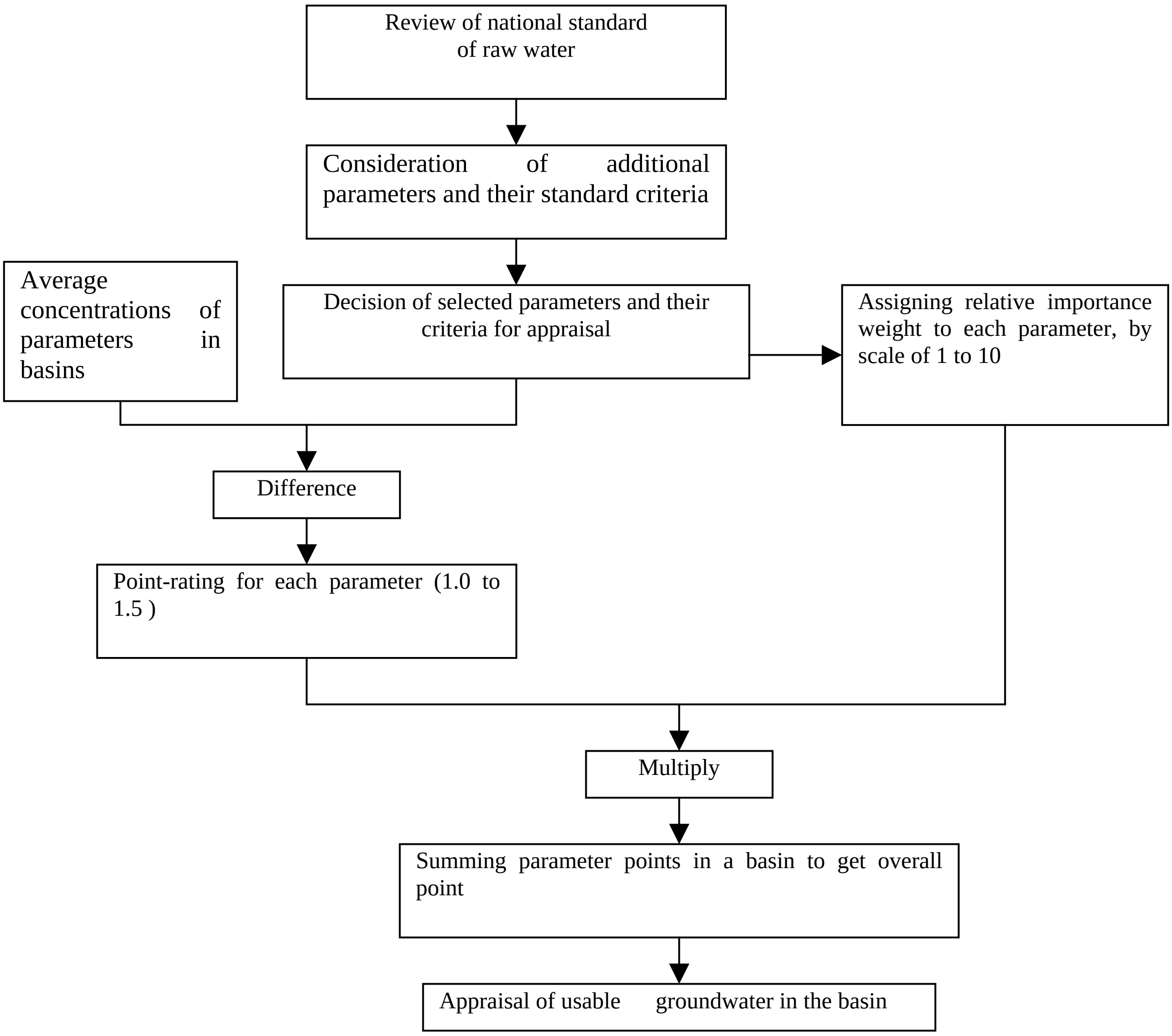


Figure-3.12 A Rating Scheme of the Quality Evaluation for Raw Water in the Basin

Table-3.2 Selected Parameters for Agricultural Raw water

Parameters used for evaluation	Standard of raw water
Zn	2.0
Fe	5.0
PH	4.5~9.5
B	1.0
Na	69 (FAO)
Chloride	142 (FAO, Surface irrigation)
TDS	450(FAO)
H_2S	0.8

(5) Assigning relative importance weight on the parameters

Table-3.3 Weighting the select parameters of raw drinking water

Parameters used for evaluation	Raw drinking water (1)		Raw drinking water (2)	
	Equal assign	Weighted assign	Equal assign	Weighted assign
NH_4-N	1.0	1.0	1.0	0.8
Ba	1.0	0.4	1.0	0.4
True Color Unit	1.0	1.2	1.0	1.4
NO_3－N	1.0	1.2	1.0	1.2
ESCHER ICHIA COLI	0.5	0.5	0.5	0.6
COLIFORMES TOTAL	0.5	0.5	0.5	0.6
H_2S	1.0	1.2	1.0	1.0
Fe	1.0	1.0	1.0	1.0
Mn	1.0	1.0	1.0	1.0
BOD	0.5	0	0.5	0
COD	0.5	0	0.5	0
Total	9.0	8.0	9.0	8.0

Table-3.4 Weighting the select parameters of agricultural water

Parameters used for evaluation	Agricultural raw water	
	Equal assign	Weighted assign
Zn	1.0	1.2
Fe	1.0	0.8
PH	1.0	1.0
B	1.0	1.2
Na	1.0	1.2
Chloride	1.0	1.0
TDS	1.0	0.8
H_2S	1.0	0.8
Total	8.0	8.0

(6) Point-rating for parameters in terms of the raw water standards

The relative point-rating for the selected parameters, that is differ from the raw water standards in various ways, will be decided based on the experts' practical suggestion. Figure-3.13 . Following table is illustrating an idea proposed by the study team.

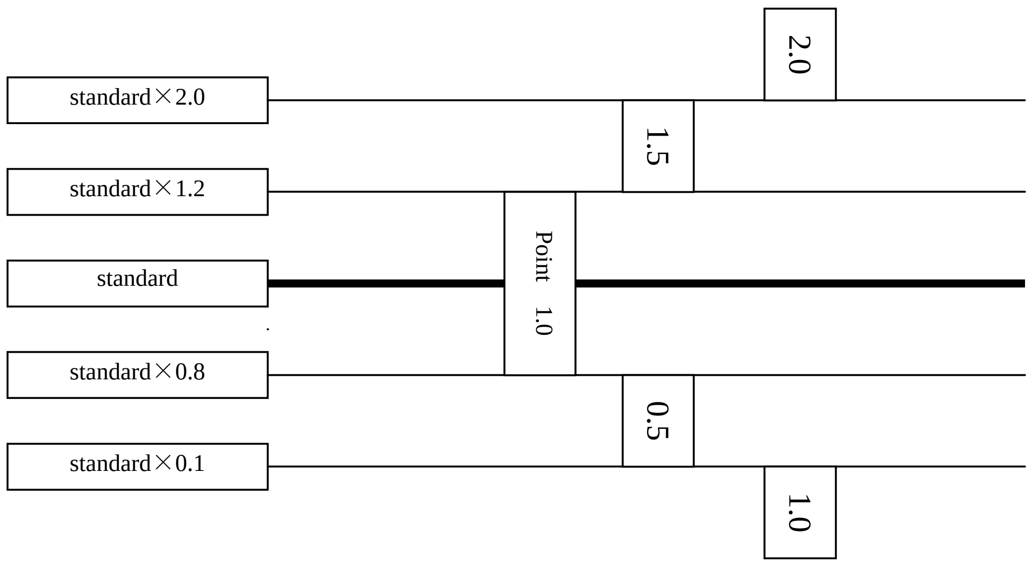


Figure-3.13 A proposed relative point-rating for the parameters

(7) Evaluation of groundwater quality for individual basin

Multiplying each parameter weight by its point-rating and summing the total provides an ecumenical evaluation of groundwater as mentioned before. But the final decision whether the groundwater is allowable or not for specific water use in the specific basin, would be issued by policy- makers in the country. A proposed rating evaluation may provide a firm base to the decision-makers.

3.5 Conclusion

- The results of water quality analysis showed that most of the wells were inadequate in chromaticity and pH-values and that some had an improper quality for drinking water in NO_3-N, Ba, ammonium, pH and SO_4 even if the water is treated by the traditional method. Most of the wells exceeded the WHO standard for drinking water in terms of Fe, alkalinity and coliform bacilli.
- The pollution sources are thought to be fertilizers (such as nitrate nitrogen and nitrite nitrogen), sewage and excreta (ammonium, H_2S, total alkalinity, coliform bacilli group, chlorides and nitrate nitrogen), natural sources (manganese, iron, chromaticity) and industrial sources (cadmium, zinc, etc.).
- The water in the Quaternary aquifer ranges from the Ca-CO_3 type in the fringe area of the basin to the Na-CO_3 type in the central area of the basin (contained in a high concentration, in particular in the central area) and it is presumed that the groundwater flow is reflected on the water quality. It is also suggested that in the Cretaceous aquifer, there is a flow running toward the central area of the basin.