6.2 Results of Water Quality Analysis

6.2.1 General Results

Arsenic, as a poisonous substance was not detected in any of the samples analyzed. Fluoride, as another poisonous substance, was found, but its level was lower than the value either of the Tanzanian temporary drinking water standard (hereafter, referred to as the Tanzania standard) or the WHO drinking water quality guideline (hereafter, it refers as the WHO guideline).

The total iron, sulfate, chloride and total dissolved solids were identified as the high content items

6.2.2 Water Qualities by Different Water Sources

Based on the analysis results from both Phase I and Phase II, the water quality by type of water source is summarized in Table 6-1. The details are shown in Table 6-3.

According to the Tanzanian standard, the percentage of samples unsuitable for drinking ranges from 33% to 89%, depending on the type of water source. However, this is mostly due to problems in pH and turbidity, and partly due to a high total-iron content. Such water sources are of little concern to human health, and can be easily treated by relatively simple methods like aeration and filtration. Therefore, these sampling sites can be considered as available sources for drinking water supplies in rural areas, even though it is nearly impossible to construct the high-level water treatment facilities there in the future.

Table 6-1 Water Qualities by Sources (2000)

Source	Rain	Dam	River	Spring	Pond	Dug Well	Borehole	Total
NOS [1]	1	3	10	14	18	62	53+1 [6]	162
NOR [2]	0	0	1	3	0	9	5	18
NOP [3]	1	3	9	11	18	53	48+1	123
NOE [4]	0	2	8	10	16	29	15+1	65
% of NOE	0	67%	89%	83%	89%	55%	33%	53%
NOU [5]	0	0	0	0	1	4	5+1	11
% of NOU	0	0	0	0	6%	8%	12%	9%

NOS [1] : Number of samples
NOR [2] : Number of repeated sampling points
NOP [3] : Number of sampled points
NOE [4] : Number of samples to exceed the Tanzanian standard
NOU [5] : Number of samples unsuitable for drinking water supply
[6] : A test well revealed high salinity but no sample could be taken from it

Essentially, the suitability of a water source must be judged on the basis of water quality in regards to human health and how difficult the water is to treat. Based on that, about 9% of the samples (11 samples) were identified as unsuitable for a drinking water supply, one from a surface water (dam, rivers and ponds), four from shallow aquifers (dug wells and pits) and six from deep aquifers (existing boreholes and test wells). The problem items are TDS, SO_4 and Cl. The percentage of samples with problem items is higher in deep aquifers than in shallow aquifers, which indicates that careful attention should be paid to water quality in development of deep groundwater in the future.

Figure 6-3 shows the trilinear diagram of a deep aquifer. Although a relatively large variation was found between samples, the tendency can be accepted to currently concentrate on domain V. In anion, chloride (Cl) + sulfate (SO_4) has a ratio higher than bicarbonate (HCO_3), and in cation, sodium (Na) + potassium (K) has a ratio higher than calcium (Ca) + magnesium (Mg), especially all the test wells distributed over domains I and IV.

Natural fresh water is generally distributed over domains I, II and the adjacent domain V. The mechanism for water quality in the study area that dominates in different types is still not clarified. On the other hand, the following processes are well known reasons that cause the Na+K ratio to be larger than the Ca+Mg ratio.

Seawater is the typical water of domain IV; therefore, the water quality tends to be concentrated in the domain by saline water intrusion. The other reason may be due to a long stagnation period of groundwater movement in water bearing formations. In groundwater, Ca+Mg tends to be replaced by Na+K, as the result of the iron exchange of soil surface; therefore, the longer the stagnation period is, the higher the ratio of Na+K becomes.

However, the saline water intrusion in the study area is limited to the coastal area, having no bad influence on the water quality of the inland area. On the other hand, the long stagnation period of groundwater in a deep aquifer can be one reason for the problem with quality. But, it is not always so simply explained, because the same water quality problem was found in a shallow aquifer. Therefore, other reasons have to be taken into consideration to reveal the mechanism of the water quality type in the study area, such as the mineralogical ingredient characteristic of the aquifer, or the influence of mineralization that occurred during tectonic movement, etc.

Figure 6-4 shows the trilinear diagram of surface water and shallow groundwater. When compared with the deep aquifer shown in Figure 6-3, water quality in the shallow aquifer is characterized by larger variation, suggesting diversification of groundwater basins in the study area and also the complicated recharge and discharge relation between shallow and deep aquifers.

6.2.3 Zoning of Water Quality

(1) Water Quality Classification

Figure 6-5 presents the hexa-diagram in the study area. According to the content of each main ingredient, the size of the hexa-diagrams gets larger in the order of surface water, shallow groundwater and deep groundwater. The water quality for all types of water sources, however, consists mostly of alkali non-carbonate salts.

The water quality of the samples with high salinity has a remarkable tendency to be divided into two groups by spatial distribution.

One group is characterized by Na-Cl concentrations to indicate the influence of the seawater intrusion. Samples, which belong to this group, are distributed along the coastal area, especially in the Kilwa district.

The other group is characterized by concentrations of Na-SO_4 and is distributed mainly in the Ruangwa and Nachingwea districts, the southern inland part of the study area..

Since sulfate tends to be changed to bicarbonate due to de-sulfurization in the reduction environment of groundwater, it is unusual for sulfate to excel in anion in ordinary groundwater. This type of water quality, however, is usually found in groundwater around mining sites. Although it has not been clarified yet what kind of mineral vein would be concerned with this type of water quality in the study area, the existence of some kinds of mineral resources are presumed in and around the area. Therefore, it would be inadequate to discuss the water quality in these two districts without taking the influence of a mineral vein into consideration.

Table 6-4 shows the summary of water quality analysis by districts.

(2) Total Iron Content

Although the high iron content has been pointed out as the problem in the drinking water supply in the study area by previous investigations, the existing characteristics of iron has not been clarified yet. Fig. 6-6 shows the distribution of the total iron content in the study area.

Iron is the fourth most abundant element in the earth's crust, and a large amount is contained in human body as an essential nutritional component. However, clothes turns yellowish brown to dark reddish-brown if washed with water containing iron above 0.3 mg/ℓ, and water would have a metallic smell if the iron content is over 0.5 - 1.0 mg/ℓ. If the iron concentration is high, coffee, tea and other beverages become purple and unsavory. In addition, various problems occur in the manufacturing of a many kinds of products if water with high iron content is used. Moreover, the pipe for the water supply would be easily clogged by iron hydroxide.

In regards to human health, the minimum daily requirement for iron is estimated at about 10-50mg/day; therefore, the superfluous ingestion of iron through drinking water is very unlikely to occur. As a matter of fact, in many cases a supplement of iron is needed rather than a reduction in iron intake.

The WHO guideline value for iron is given as 0.3 mg/ℓ, but this is not based on effects on health. The iron value was set as such due to consumer complaints about the staining of laundry and sanitary ware. The Tanzanian iron standard is set at 1.0 mg/ℓ.

Groundwater with iron content over the Tanzanian standard was found from all districts in the study area except Newala. However, a belt of high iron content in groundwater can be clearly identified in the southwestern part of the study area, especially in the eastern part of the Masasi and Nachingwea districts. This distribution is in consistency with the area of basement rocks composed mainly of pre-Cambrian metamorphic rock series.

In the study area, nearly 92% of water samples have iron concentrations below 2mg/ℓ. The highest iron content, 14.35 mg/ℓ, was found in a sample from the Mehinwa River in the Lindi region. Even this value is smaller than the iron content of fish or green vegetables, which contain 20-150 mg/kg of iron. Therefore, it can be considered that these water sources will not cause any significant health problems.

Iron usually exists in groundwater in the form of ferrous bicarbonate [$Fe(HCO_3)_2$]. Particularly, in colorless and transparent groundwater with pH below 7(seven), iron almost always takes this form. Ferrous bicarbonate tends to oxidize. When left and/or aerated after withdrawal, ferrous bicarbonate will change to ferric hydroxide [$Fe(OH)_3$], which is brown in color and insoluble. In Bangladesh, there was a case where the dissolved iron content of a well water sample decreased from 8 mg/ℓ to 0.5 mg/ℓ, after agitating for 10 minutes with a grass bar, and then leaving for about one hour.

The results of the total iron content analysis were different largely by the different pretreatment methods. In Phase II, two kinds of pretreatment methods were adopted and they are compared in Table 6-2. Two samples were taken from each point and put into bottles. In order to prevent oxidation of iron and other substances, sulfuric acid was added into one of the bottles to adjust the pH to about 2. No acid was added to the other bottle. The samples were left for two days and then filtered through A5 filter paper before iron analysis. The pH at the time of analysis of the samples without the added sulfuric acid is also shown in the table.

Although the pH of the samples from rivers fell, the pH of the samples from groundwater went up.

Table 6-2 Difference in Total Iron Content by Pretreatment Method

Sampling Points	Source	Total Iron (mg/ℓ)		pH	
		Sulfuric Acid	Filter	When Sampling	When Analyzing
Nyengedi	River	1.15	0.26	8.6	7.9
Mahiwa	River	14.35	0.34	8.1	7.8
Chiwerere	Dug Well	2.6	Nd	7.3	8.2
Kilosa	Dug Well	1.0	0.01	6.8	7.7
Lukuledi	Borehole	0.15	0.01	7.6	8.0
Mlingula	Borehole	1.32	0.43	6.7	7.5
Kitangari	Borehole	0.15	0.04	4.1	4.9
Mnazimoja	Borehole	1.02	0.07	7.2	7.8
Mpapura	Borehole	0.5	0.13	7.0	7.8
Range		0.15～14.35	Nd～0.43	4.1～8.6	4.9～8.2
Average		2.73	0.14	7.0	7.5

Nd : No detected.

From the nine samples used for this comparison, the total iron content of the samples with an addition of sulfuric acid ranged from 0.15-14.35 mg/ℓ, and averaged 2.73mg/ℓ. About 60% (6 out of 9) of the samples have iron concentrations over the Tanzanian standard. The range of total iron content of the samples without an addition of acid was Nd - 0.43 mg/ℓ. All samples have iron concentrations less than the Tanzanian standard, and the average value was only 1/20 of that of the former.

Although iron is not a health-concerning item, it is necessary to eliminate iron in some places in the study area to supply water good in taste and suitable for laundry and other kinds of utilities. Iron can be eliminated from water by simple treatment methods such as aeration and filtration.

(3) Sulfate

High sulfate (SO_4) content was detected from several wells in the study area. Water with high sulfate content does not only have disagreeable taste and odor, but also associates with diarrhea and even the risk of dehydration.

Some villagers in the study area seem to sense the difference in sulfate concentration. The two wells in Mkotukuyana village in the Nachingwea district are located only about 20m apart from each other, but the taste of the water from each is different. One is said to be salty and the other soft. Actually, it is not a salty, but an unpleasant taste. No large difference in concentration was found for most items except sulfate. The sulfate level in the so called salty well was 480 mg/ℓ, which exceeds the WHO guideline value, while in the other well it was 180 mg/ℓ, less than half of the former. This finding seems to indicate that the sulfate concentration is the possible cause for the different taste of the well water. In Ruangwa and Nachingwea, the wells with bad-tasting water due to high sulfate are not used for drinking purposes. People fetch water from other sources several kilometers away from the villages.

Figure 6-7 shows the sulfate distribution in the study area. All high sulfate samples, except one point in the Kilwa district, concentrate in Ruangwa and Nachingwea. Especially in Ruangwa, a high sulfate groundwater area extends from the central to the northern part.

Geologically, this area is close to the boundary of pre-Cambrian metamorphic rock series and Mesozoic sedimentary rocks. Several kinds of metal mineral resources are presumably abundant in this area, suggesting that mineral veins have influence on groundwater quality.

(4) Salinity

Salinity is another problem in groundwater quality in the study area next to high sulfate. The drilled test well in Ndomoni village of the Nachingwea district was found to have a very high electricity conductivity (EC), exceeding 7000 μS/cm. High EC does not always mean a high content of salt (NaCl), but it indicates a high value of dissolved ion. This kind of water is not only obviously too salty (bad-tasting) for human drinking, but also can hardly be used for most of crops, as shown in the following data from the American Salinity Laboratory.

EC (μS/cm) Related to Yield Potential

Yield potential	100%	90%	75%	50%	0%
Cotton	7700	9600	13000	17000	27000
Soya bean	5000	5500	6200	7500	10000
Rice	3000	3800	5100	7200	11500
Maize	1700	2500	3800	5900	10000
Cowpea	1300	2000	3100	4900	8500

About 10% of water sources in the study area have a high level of total dissolved solids (TDS) over the Tanzanian standard. The Tanzanian standard for TDS, as an indicator of salinity, is set at 2000mg/ℓ, and the WHO guideline value is1000 mg/ℓ. According to these standards and guideline values, water of high salinity can only be considered unsuitable for a drinking water supply.

However, few reports can be found on health problems caused by salinity if the main ingredient of salt is sodium chloride (NaCl) because NaCl itself is not a poisonous substance at all. As a reference, a report on salinity concerning animal growth is given below.

Maximum Level of Drinking Water Salinity (mg/ℓ)

	Desirable for healthy growth	Maximum for good health	Maximum tolerable for limited period
Beef Cattle	4000	5000	10000
Dairy cattle	3000	4000	6000
Sheep, goats	6000	13000	13000
Pigs	2000	3000	4000
Poultry	2000	3000	4000

Source : Australian water Resources Council

Figure 6-8 shows the distribution of TDS in the study area. Besides the area of high sulfate, a high TDS belt-like zone has also been found along the coastline in the eastern part of the study area. The high TDS in this zone is obviously due to sodium chloride (NaCl) rather than sulfates, suggesting the occurrence of seawater intrusion.

Table 6-3 Summary of Water Quality Analysis Result by Water Sources (2000)

Source	Rain	River		Dam		Pond and Lake		Spring		Dug Well		Borehole	
Num. of smpl pt	1	9		3		18		11		53		48	
Terms	Value	Range	NOE*1	Range	NOE	Range	NOE	Range	NOE	Range	NOE	Range	NOE
pH	7.27	5.8-8.1	**2**	6.3-7.9	**1**	4.7-8.3	**5**	5.4-7.91	**4**	4.1-8.5	**20**	4.1-9.3	**8**
Temperature(℃)	23.4	23.7-29.1	no	24.6-29	no	20.4-32.2	no	24.4-30.4	no	23.6-35.6	no	23.3-31.4	no
EC(μS/cm)	140	113-2644	no	192-1010	no	57-5420	no	129-1763	no	68-4650	no	71-7100	no
Coliform	nd*3	==	**5**	==	**1**	==	**10**	==	**5**	==	**35**	==	**19**
Do(mg/l)	5.68	1.8-5.8	no	2.6-4.8	no	2.1-6.2	no	2.1-7.2	no	1.3-6.3	no	0.4-6.8	no
Turbidity(UTN)	0	0-40	**2**	107-337	**2**	4-385	**7**	0-5	0	1-1800	**18**	0.1-160	**5**
Na(mg/l)	0.682	12-459	no	64-152	no	6-831	no	18-245	no	7.4-863	no	13-1095	no
K(mg/l)	1.3	3-16	no	3-32	no	1.6-45.4	no	2.4-17	no	0.8-73	no	2-103	no
Ca(mg/l)	3.87	nd-27	no	3.6-33	no	nd-51.4	no	nd-67	no	nd-69	no	nd-173	no
Mg(mg/l)	0.69	0.09-55	no	3.1-30	no	0.1-57.4	no	0.59-40	no	0.5-187	no	0.1-196	no
Fe(mg/l)	0.03	nd-14.35	**1**	0.05-3.28	**2**	nd-2.8	**3**	nd-2.5	**3**	nd-9.2	**11**	nd-6.1	**5**
Mn(mg/l)	---	nd-0.2	0	nd	0	nd-3.3	**2**	nd-0.2	0	nd-1.2	**4**	nd-0.8	**2**
F(mg/l)	nd	nd-1.69	0	0.34-0.42	0	nd-1.8	0	nd-0.8	0	nd-2.5	0	nd-1.9	0
As(mg/l)	---	nd	0	nd	0	nd	0	nd	0	nd	0	nd	0
HCO_3(mg/l)	---	2.3-248	no	18-213	no	14-324	no	7-244	no	5-492	no	11-401	no
SO_4(mg/l)	nd	nd-375	0	nd-50	0	nd-593	0	nd-130	0	1-1430	**3**	nd-1400	**2**
Cl(mg/l)	---	16-247	0	13-95	0	8-607	0	13-168	---	7-884	**1**	24-1261	**1**
NO_3-N(mg/l)	0.1	nd-1.2	0	nd-2.5	0	nd-2.3	0	nd-4.3	0	nd-34	0	nd-23	0
NH_3-N(mg/l)	0.04	nd-0.17	no	0.02-0.13	no	nd-0.4	0	nd-0.06	no	nd-2	0	nd-0.9	0
TDS(mg/l)	15	87-1298	0	455-568	0	220-2169	**1**	110-631	0	71-2582	**4**	88-2503	**3**

NOTES
*1： NOE = Number of samples to Exceed Tanzania Standard of Water Quality
*2： no = No standard value was established
*3： nd = No detected
*4： == No available figure
*5： --- No observation result

Table6-4 Summary of Water Quality Analysis Result by Districts (2000)

Region	Mtwara								Lindi									
District	Mtwara		Masasi		Newala		Tandahimba		Kilwa		Lindi		Ruangwa		Nachingwea		Liwale	
Num. Of smpl	23(5)		29(7)		9		6(1)		22(1)		31(4)		12		16		13	
Terms	Rng*1	NOE*2	Rng	NOE	Rng	NOE	Rng	NOE	Rng	NOE	Rng	NOE	Rng	NOE	Rng	NOE	Rng	NOE
pH	5.4-8.3	**5**	5.6-7.6	**8**	4.1-8.2	**3**	5.9-7.6	**3**	4.1-8	**5**	4.9-9.3	**9**	6.1-8.5	**1**	5.8-7.9	**1**	4.65-775	**8**
Temp.(℃)	24.2-30.8	no	23.6-30.5	no	20.5-35.6	no	20.4-28	no	26.5-32	no	23.3-31.4	no	25.2-29.4	no	25.2-29.8	no	25.5-29.4	no
EC(μS/cm)	189-2700	no	68-1580	no	92-573	no	102-470	no	102-7100	no	113-2510	no	105-4630	no	93-5100	no	57-2588	no
Coliform	==*3	**6**	==	**9**	==	**3**	==	**2**	==	**16**	==	**17**	==	**6**	==	**7**	==	**9**
Do(mg/l)	2-5.2	no	1.6-3.8	no	2.1-5.8	no	2.9	no	2.9-3.9	no	1.8-5.8	no	3.4-7.2	no	1.3-6.8	no	0.39-6.23	no
Tbdty(UTN)	0.5-160	**6**	2-856	**8**	4-52	**1**	6-16	0	5-1800	**5**	0-337	**5**	2-197	**2**	1-385	**3**	0-206	**7**
Na(mg/l)	64-608	no	13-295	no	11-269	no	20-102	no	27-962	no	12-1095	no	11-521	no	9-319	no	5.8-300	no
K(mg/l)	3-45	no	2-34	no	4-25	no	3-20	no	3-103	no	3-33	no	2.4-24	no	2-44	no	0.8-15	no
Ca(mg/l)	nd-173	no	nd-23	no	nd-9	no	nd-25	no	nd-69	no	nd-33	no	nd-41	no	nd-33	no	0.05-51	no
Mg(mg/l)	nd-29	no	0.06-196	no	2.5-13	no	3-9	no	0.5-66	no	nd-32.7	no	0.5-187	no	0.2-95	no	2.6-57	no
Fe(mg/l)	0.01-3.3	**3**	nd-9	**5**	0.01-0.4	0	0.03-2	**1**	0.01-2.5	**3**	nd-14.35	**4**	nd-9.2	**2**	nd-6.1	**2**	0.04-1.33	**4**
Mn(mg/l)	nd-0.3	0	nd-0.3	0	nd-0.3	0	nd-0.05	0	nd-0.6	**1**	nd-1	**2**	nd-1.2	**2**	nd-0.8	**2**	nd-3.3	**1**
F(mg/l)	nd-1.4	0	nd-1.9	0	0.2-0.38	0	nd-0.23	0	nd-1.1	0	nd-1.91	0	0.6-2.5	0	0.3-1.7	0	0.04-1.25	0
As(mg/l)	nd	0	nd	0	nd	0	nd	0	nd	0	nd	0	nd	0	nd	0	nd	0
HCO3(mg/l)	75-276	no	2-352	no	nd	no	11-32	no	8-465	no	7-401	no	31-492	no	5-380	no	13-130	no
SO4(mg/l)	nd-280	0	nd-104	0	nd-16	0	nd-7	0	nd-800	**1**	nd-560	0	11-1430	**3**	nd-1015	**1**	1-11	0
Cl(mg/l)	85-200	0	18-325	0	24	0	73-123	0	26-1261	**1**	12-364	0	13-884	**1**	12-644	0	7-74	0
NO3-N(mg/l)	nd-3.2	0	nd-8	0	nd-1.3	0	nd-1.2	0	nd-34	0	nd-7.5	0	nd-8.5	0	nd-2	0	nd-3.8	0
NH3-N(mg/l)	nd-0.6	no	nd-0.2	no	0.1-2	no	0.01-0.3	no	nd-2.04	no	nd-0.85	no	nd-1.2	no	nd-2	no	nd-0.42	no
TDS(mg/l)	346-1400	0	71-1021	0	88-240	0	100-350	0	105-2582	**4**	87-2990	**1**	322-2150	**2**	102-1735	0	114-423	0

NOTES
*1： Rng ＝ Range
*2： NOE ＝ Number of samples to Exceed Tanzania Standard of Water Quality
*3： ＝＝ No available figure
*4： --- No observation result
*5： no ＝ No standard value was established
*6： nd ＝ No detected

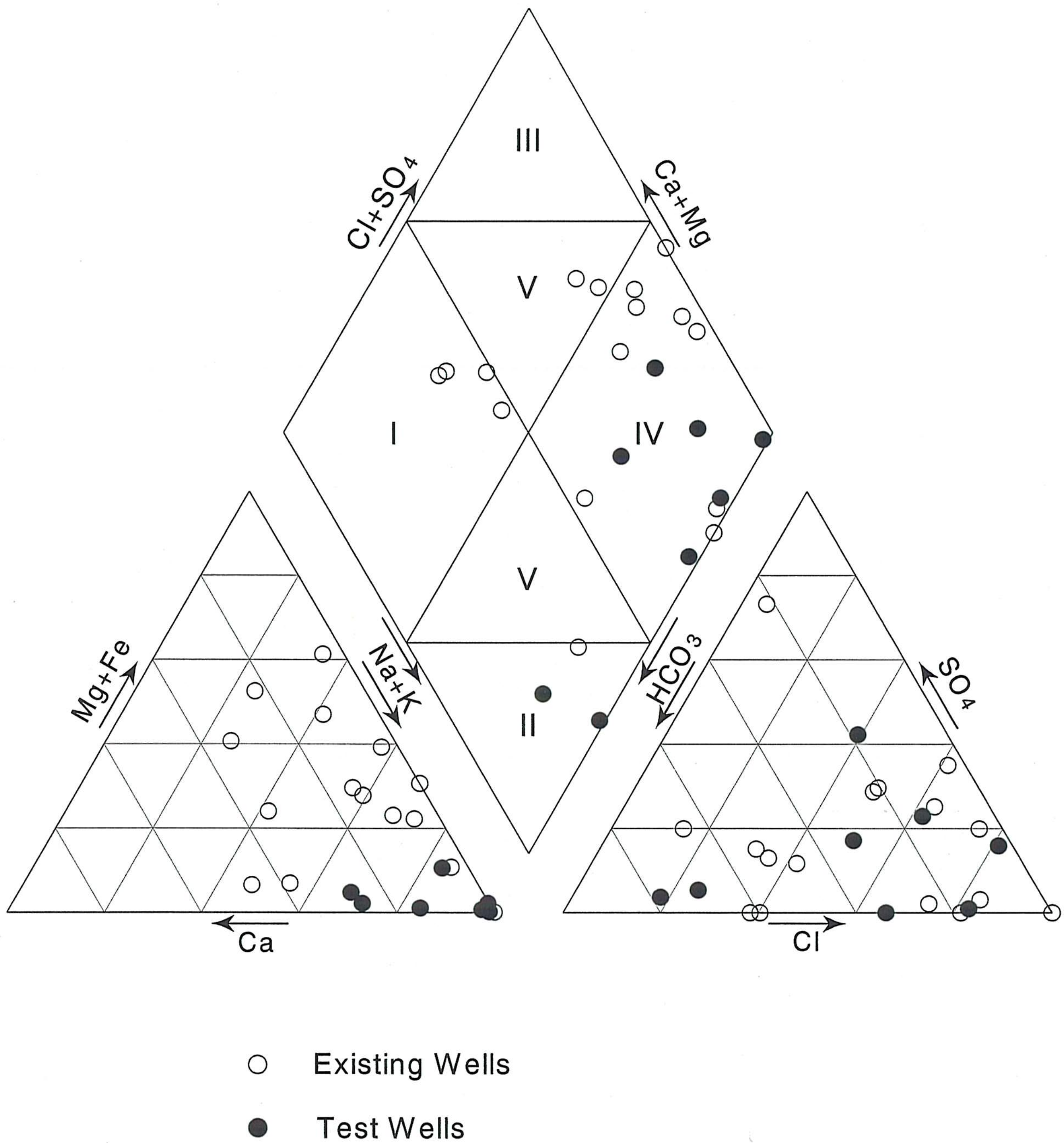

Fig. 6-3	Trilinear Diagram of Deep Aquifer (2000)

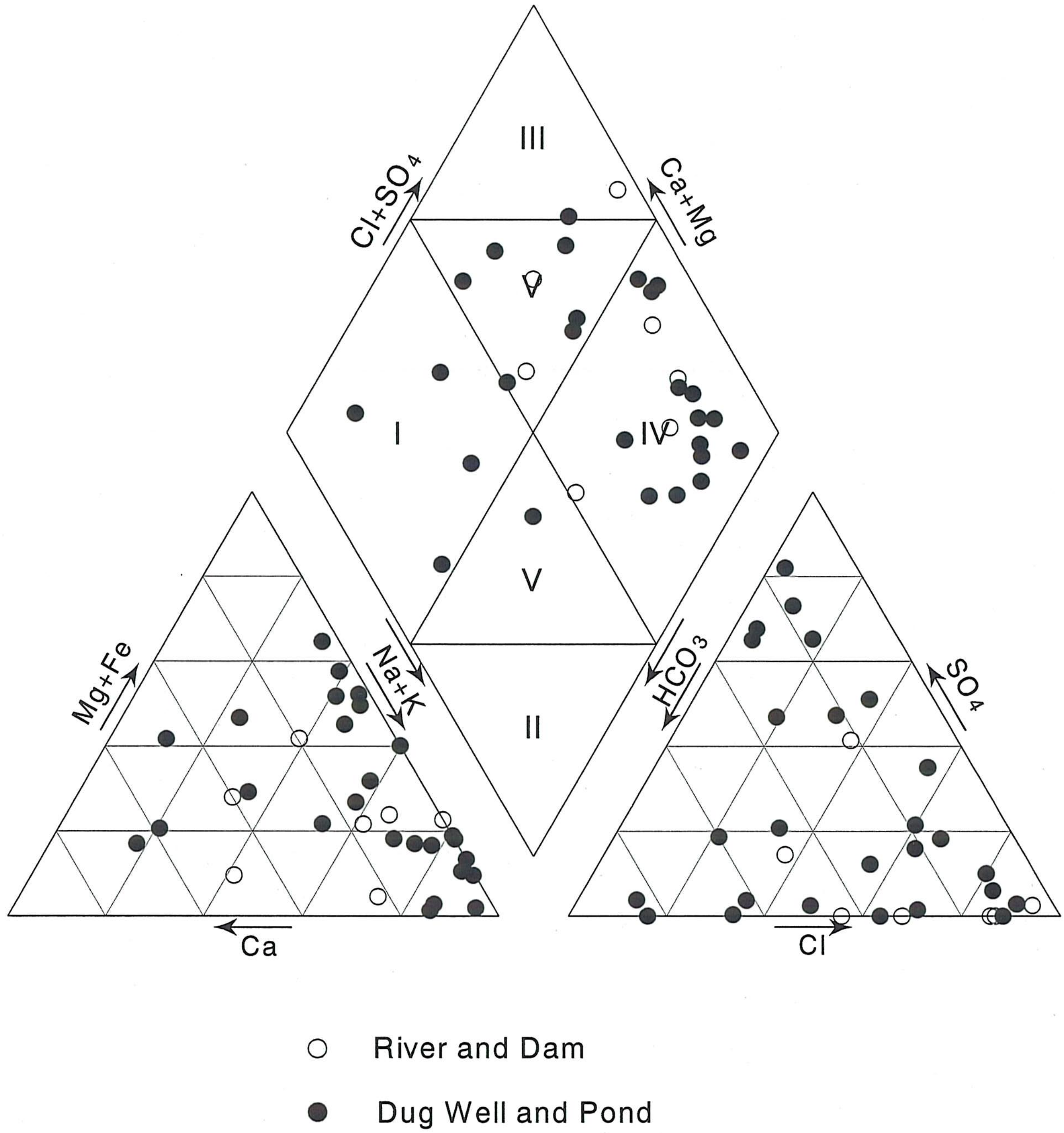

Fig. 6-4	Trilinear Diagram of Shallow Aquifer and Surface Water (2000)

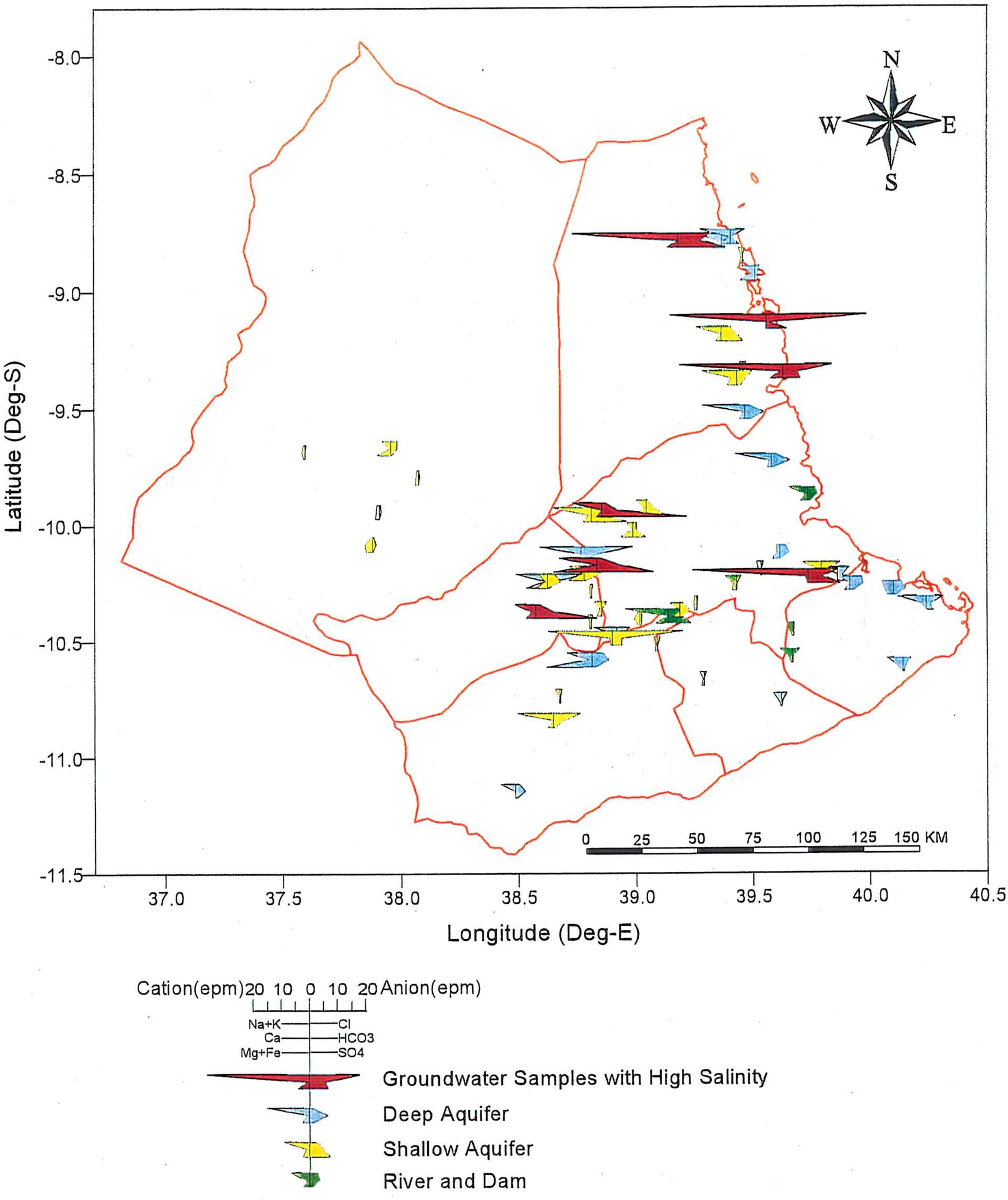

Fig. 6-5	Hexa Diagram