Chapter 3
Water Quality Analysis

CHAPTER 3 WATER QUALITY ANALYSIS

3.1 Introduction

According to the interviews with the water engineers of the six regions in IDB, the information collected suggested the existence of areas with high fluoride contamination; however, the distribution of fluoride covering the water source of the whole IDB had not been clarified. Moreover, the origin of the fluoride and other water pollution conditions are not fully understood. Therefore, a water quality survey was carried out in the Study, the purposes of which are summarized in Table 3-1.

Table 3-1 Contents of Water Quality Survey

Purpose	Survey Method	Water Quality Survey Point
i) Overall picture of fluoride distribution	1) Collecting existing data of water quality survey in IDB 2) Simplified water quality test (this study) 3) Inventory survey of existing water supply facilities (this study)	Water quality data (including existing data) was collected relatively uniformly over IDB.
ii) Clarification of origin of fluoride	1) Laboratory test of water quality (this study)	In addition to item "i" (above), checkpoints were selected in the areas with a conspicuously high concentration of fluoride in order to clarify the relationship between the various minerals and the fluoride concentration in the water source.
iii) Other water pollution conditions	1) Simplified water quality test (this study) 2) Laboratory test of water quality (this study)	Distributions of the other water quality items (iron, manganese, nitrate, ammonium, coli bacteria, etc.) except fluoride were investigated at the survey points in item "i" mentioned above.

3.1.1 Methodology

(1) Simplified Water Quality Test

Approximately 200 villages were selected for simplified water quality tests in consideration of their availability of water source conditions. Moreover, the survey focused on the blank areas of data and/or the areas where fluoride contamination was presumed by other information. The test was carried out two times during this study. The first and second simplified water quality tests were carried out from February to March 2006 for 264 sites in 183 villages and August 2006 for 317 samples in 266 villages, respectively. The following water quality items were measured in the field by simplified water inspection instruments and field kits.

Measurement by simplified water inspection instruments:
Water temperature, pH, electric conductivity (EC), oxidation-reduction potential (ORP)
Measurement by field kit:
Sulfur ion, fluoride, arsenic, ammonia ion, nitrate ion, iron, manganese, coliform bacteria.

Also, the water quality survey was conducted in the same way during the inventory survey of existing water supply facilities in the Study.

Figure 3-1 Simplified Water Quality Test on Site

(2) Laboratory Test of Water Quality

Laboratory tests of water quality were conducted in order to evaluate the water resources in IDB as to groundwater suitability for drinking water, availability of other water sources, water treatment method and so on. Water quality parameters for the test are shown in Table 3-2, which included additional parameters other than those used for the provisional water quality standards related to drinking water in Tanzania.

Water samples were collected during the second simplified water quality test. The water samples taken from monitoring wells constructed in the Study were collected from August 2006 to September 2007 and then immediately brought to a laboratory.

Table 3-2 Tanzanian Standards for Drinking Water Quality by Items

Aspect and Items			Unit	Tanzanian Standard (2003) *1	WHO Guideline (2004) *2
Microbial Aspects	1	Total coliform bacteria	count/100ml	0	-
	2	Escherichia Coli	count/100ml	0	0
Chemicals that are of health significance	3	Cadmium (Cd)	mg/l	0.05	0.003
	4	Cyanide (CN)	mg/l	0.2	0.07
	5	Lead (Pb)	mg/l	0.1	0.01
	6	Arsenic (As)	mg/l	0.05	0.01
	7	Mercury (Hg)	mg/l	0.001	0.001
	8	Selenium (Se)	mg/l	0.05	0.01
	9	Barium (Ba)	mg/l	1	0.7
	10	Fluoride (F)	mg/l	4	1.5
	11	Hexavalent-chromium (Cr6+)	mg/l	0.05	-
	12	Total chromium (T-Cr)	mg/l	-	0.05
	13	Nitrate (NO3-N)	mg NO3/l	75	50
	14	Nitrite (NO2-N)	mg NO2/l	-	3 / 0.2 *3
	15	Boron (B)	mg/l	-	0.5
	16	Nickel (Ni)	mg/l	-	0.02
	17	Antimony (Sb)	mg/l	-	0.02
	18	Molybdenum (Mo)	mg/l	-	0.07
	19	Manganese (Mn)	mg/l	0.5	0.4
	20	Organic Carbon (as carbon in Chloroform)	mg/l	0.5	-
Acceptability aspects	21	Acceptability aspects	Hardness	600	600
	22	Calcium (Ca)	mg/l	100	-
	23	Magnesium (Mg)	mg/l	1000	-
	24	Iron (Fe)	mg/l	1	-
	25	Zinc (Zn)	mg/l	15	-
	26	Copper (Cu)	mg/l	3	2
	27	Chloride (Cl-)	mg/l	-	-
	28	Residue*4	mg/l	-	-
	29	Total filterable residue*5	mg/l	2,000	-
	30	Anionic surface active agents (as ABS)	mg ABS/l	2	-
	31	Phenols	mg/l	0.002	-
	32	Hydrogen sulfide (H_2S)	mg/l	-	-
	33	Ammonium (NH_3+NH_4)	mg/l	-	1.5
	34	Total nitrogen (Excluding NO_3)	mg/l	1	-
	35	BOD	mg/l	6	-
	36	Potassium permanganate consumption	mg/l	20	-
	37	pH	-	6.5 - 9.2	
	38	Taste	dilution	not objectionable	-
	39	Odour	dilution	not objectionable	-
	40	Colour	mg Pt/l	50	15
	41	Turbidity (Tr)	NTU	25	5
	42	Temperature	℃	-	-
	43	Conductivity (EC)	mS/m	-	-
	44	Residual chlorine (Cl)	mg/l	-	-
	45	Sulfate (Mg+Na Salts)	mg/l	-	-
Water qualityitems related to the characteristicsof groundwater	46	Sodium (Na)	mg/l	-	-
	47	Potassium (K)	mg/l	-	-
	48	Bicarbonate (HCO_3^-)	mg/l	-	-
	49	Total alkalinity	mg/l	-	-
	50	Sulfate (SO_4^{2-})	mg/l	-	-

*1: "National Environmental Standards Compendium" Tanzania Burea of Standards, 2003
*2: "WHO Guideline for Drinking Water Quality Third Edition", World Health Organization, Genova, 2004
*3: Short term / long term
*4: Residue is equal to [Total solids - Total dissolved solids]
*5: Total filterable residue is equal to Total dissolved solids (TDS).
(grey box) Items adopted for water quality evaluation.

3.1.2 Survey Locations

Survey points for the simplified water quality test and water sampling points for the laboratory test are shown in Figure 3-2.

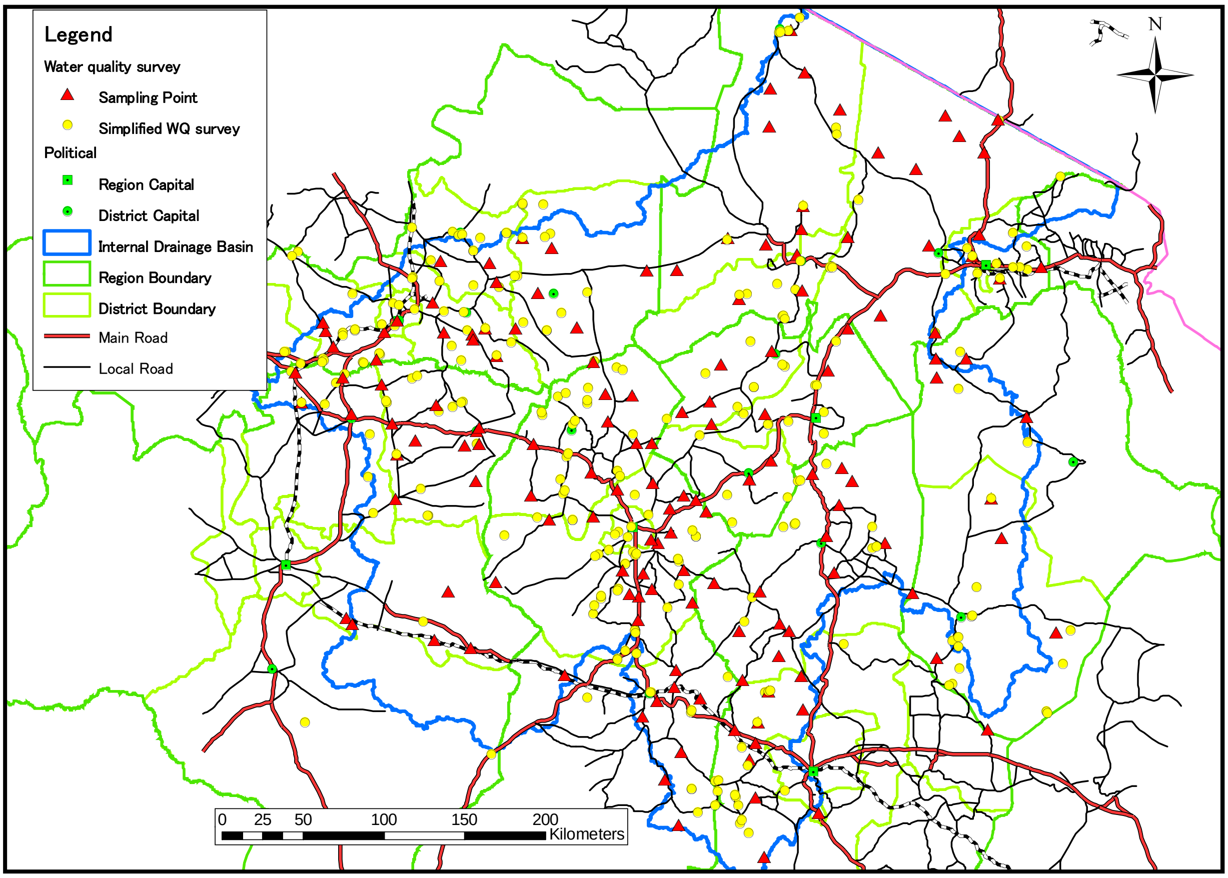


Figure 3-2 Location of Water Quality Survey Points

3.2 Surface Water Quality

3.2.1 Major Lakes

Table 3-3 shows the water quality of the major lakes in IDB and around Tanzania. The fluoride concentration of the lakes in IDB ranges from 0.3 to 966 mg/l; the highest being Lake Natron, although Lake Magadi, located within the Kenyan border of the Lake Natron Sub-basin (E Sub-basin), is reported to have the highest fluoride concentration (1,550 mg/l) in East Africa. The lakes in IDB are characterized by their generally very shallow water depth caused by topographical or geological features of the Gregory Rift Valley (Refer to Chapter 2, 2.3), as represented by Lake Natron, Lake Manyara, and Lake Eyasi which all have a depth of three meters or less. Another characteristic is that these are alkaline lakes that contain very high levels of sodium (Na) and potassium (K).

Table 3-3 Water Quality of Lakes in IDB and around Tanzania

	No	Name	Area (km^2)	Depth (m)	Vol (Km^3)	Altitude (m)	pH	Alkali	Na	K	Ca	Mg	Cl	SO4	F	SiO2
Gregory (Eastern) Rift Valley	1	Turkana	7,600	75	251	400	10	23	48	1	0	0	21	1	**9**	1
									767	22	5	2	440	37		22
	2	Baringo	129	8	?	965	9	4	95	13	12	3	25	20	**?**	24
	3	Bogoria	34	?	?	963	11	965	28,400	387	?	?	6,390	216	**1,060**	260
	4	Nakuru	45	3	?	1,758	?	?	79	2	?	?	9	1	**?**	1
	5	Naivasha	195	18	?	1,884	8	2	24	12	16	5	7	5	**1**	25
	6	Magadi	104	?	?	575	11	3,170	132,000	2,280	?	?	84,400	2,190	**1,550**	1,055
															437	
	7	Natron	900	?	?	610	10	2,096	62,700	1,080	?	?	18,300	4,420	**966**	155
	8	Manyara	470	3	?	960	10	806	2,500	8	10	1	1,173	230	**?**	10
									21,500	94		30	8,670	1,056		19
														2,280		
	9	Eyasi	1,050	?	?	1,030	?	?	4,480	55	?	4	4,360	340	**?**	?
	10	Basuto	-		-	-	8.4	-	91	-	-	-	-	-	**2.2**	-
	11	Duluti	-	-	-	-	9.2	-	66	-	-	-	-	-	**3.0**	-
	12	Tlawi	-	-	-	-	6.6		107	-	-	-	-	-	**0.4**	-
	13	Basutoghang	-	-	-	-	7.2		54	-	-	-	-	-	**0.3**	-
	14	Kindai					8.5		1,236						**1.3**	
	15	Singida					9.0		590						**1.1**	
	16	Victoria	68,500	90	2,700	1,134	8	1	10	3	5	4	4	5	**0**	17
Western Rift Valey	17	Kyoga	2,047	?	?	1,037	?	?	28	7	14	7	7	5	**1**	30
	18	Albert	5,900	55	150	617	9	7	4	2	1	3	1	1	**?**	0
									25	10	2	8	6	2		
	19	George	258	4	?	914	9	2	1	0	1	1	0	0	**?**	1
									14	3	12	8	6	3		
	20	Edward	2,200	11	78	914	9	10	5	2	1	4	1	1	**?**	1
									23	11	2	10	5	2		
	21	Kivu	2,250	485	570	1,163	9	16	6	2	1	7	1	0	**2**	1
									20	10	1	14	6	1		
	22	Tanganyika	33,500	1,470	18,900	773	9	7	3	1	1	4	1	0	**1**	?
									24	7	2	14	5	0		
	23	Rukwa	2,716	10	?	793	?	?	41	2	?	?	9	1	**?**	1
	24	Malawi	25,000	770	6,150	475	9	2	1	0	1	0	0	0	**?**	1
									21	4	12	5	3	1		

(shaded) : within IDB (Modified Table 14, P349-350 in Thomas Schluter (1997) : Geology of East Africa) Unit: mg/L

3.2.2 Surface Water Quality (rivers, dams, ponds and springs)

Surface water quality in IDB was analyzed using existing records, simplified water quality survey and inventory survey for rivers, dams and ponds at 175 locations and for springs at 154 locations. The average water quality and conditions according to concentration levels of fluoride (F), electric conductivity (EC) and pH, respectively, are arranged in Table 3-4. Figure 3-3 and 3-4 show the distribution of fluoride concentration (F) and electric conductivity (EC) respectively.

Among the six regions in IDB, the highest fluoride levels in rivers, dams and ponds was observed in Shinyanga Region (average: 2.4 mg/l) and in springs was observed in Arusha Region (average: 2.6 mg/l). According to the "Arusha Master Plan (2000)", Ayahata Spring in Endaberg Village, Babati District, Manyara Region, had the highest concentration of 66 mg/l, followed by Kituma River in Lositete Village, Karatu District, Arusha Region, of 44 mg/l. Seven percent of the rivers, dams and ponds and 12 % of the springs exceeded the water quality standard of fluoride for drinking water in Tanzania (fluoride concentration of 4 mg/l or less).

Spring water showed higher electric conductivity (EC) than the rivers, dams and ponds. Among the six regions, Dodoma Region had the highest EC (average: 111.1 mS/m) followed by Singida Region (average: 84.6 mS/m). Although Tanzania has no standard value for EC, levels exceeding 150 mS/m are generally unsuitable for drinking. Three percent of the rivers, dams and ponds and nine percent of the springs exceeded this value.

In contrast to EC, the pH of surface water was comparatively lower in rivers, dams and lakes. Although the Tanzanian standard for pH of drinking water ranges from 6.5 to 9.2, two percent of the springs and four percent of other surface waters (river, dam and pond) showed levels below pH 6, whereas one percent of the springs and six percent of other surface waters showed levels above pH 9.

Table 3-4 Fluoride, EC and pH of Surface Water in IDB

Fluoride

Region	Dam, Pond, River and Rain				Spring			
	No.	Minimum	Maximum	Average	No.	Minimum	Maximum	Average
Arusha	93	0.2	44.0	1.5	110	0.1	66.0	2.6
Manyara	5	0.2	5.0	2.2	12	0.0	4.0	1.3
Dodoma	3	0.4	1.0	0.7	10	0.2	2.7	1.2
Tabora	25	0.1	1.5	0.7	3	0.4	1.4	0.9
Shinyanga	25	0.8	6.4	2.4	4	1.2	3.5	2.1
Singida	24	0.0	5.0	2.2	15	0.3	8.7	2.3
IDB	175	0.0	44.0	---	154	0.0	66.0	---

Fluoride (mg/l)	Dam, Pond and River		Spring	
	No.	%	No.	%
0-0.4	45	26	32	21
0.4-0.8	35	20	48	31
0.8-1.5	35	20	24	16
1.5-4	48	27	31	20
4-8	11	6	13	8
8-	1	1	6	4
Total	175	100	154	100

Unit: mg/l

EC

Region	Dam, Pond, River and Rain				Spring			
	No.	Minimum	Maximum	Average	No.	Minimum	Maximum	Average
Arusha	93	4.0	490.0	34.3	106	6.6	324.0	56.8
Manyara	5	9.2	58.1	26.8	12	5.3	400.0	83.1
Dodoma	3	19.6	54.5	31.7	7	28.9	285.0	111.1
Tabora	23	8.3	98.9	35.0	2	13.2	33.8	23.5
Shinyanga	25	10.8	56.1	29.0	4	9.4	20.2	13.3
Singida	25	4.4	180.0	49.3	14	17.2	350.0	84.6
IDB	174	4.0	490.0	---	145	5.3	400.0	---

EC (mS/m)	Dam, Pond and River		Spring	
	No.	%	No.	%
0-10	22	13	8	6
10-50	122	70	86	59
50-150	26	15	38	26
150-300	3	2	10	7
300-1000	1	1	3	2
1000-	0	0	0	0
Total	174	100	145	100

Unit: mS/m

pH

Region	Dam, Pond, River and Rain				Spring			
	No.	Minimum	Maximum	Average	No.	Minimum	Maximum	Average
Arusha	93	5.7	9.4	7.4	112	5.9	8.9	7.3
Manyara	5	7.4	9.2	8.3	12	6.8	8.2	7.6
Dodoma	3	7.6	8.8	8.3	10	6.6	7.7	7.2
Tabora	21	6.4	10.0	8.1	3	6.4	7.6	6.8
Shinyanga	25	6.8	8.9	7.9	4	6.5	7.3	6.9
Singida	16	2.1	11.0	7.8	10	5.6	9.2	7.2
IDB	163	2.1	11.0	---	151	5.6	9.2	---

pH	Dam, Pond and River		Spring	
	No.	%	No.	%
4-5	0	0	0	0
5-6	6	4	3	2
6-7	41	25	45	30
7-8	52	32	75	50
8-9	55	34	27	18
9-10	9	6	1	1
Total	163	100	151	100

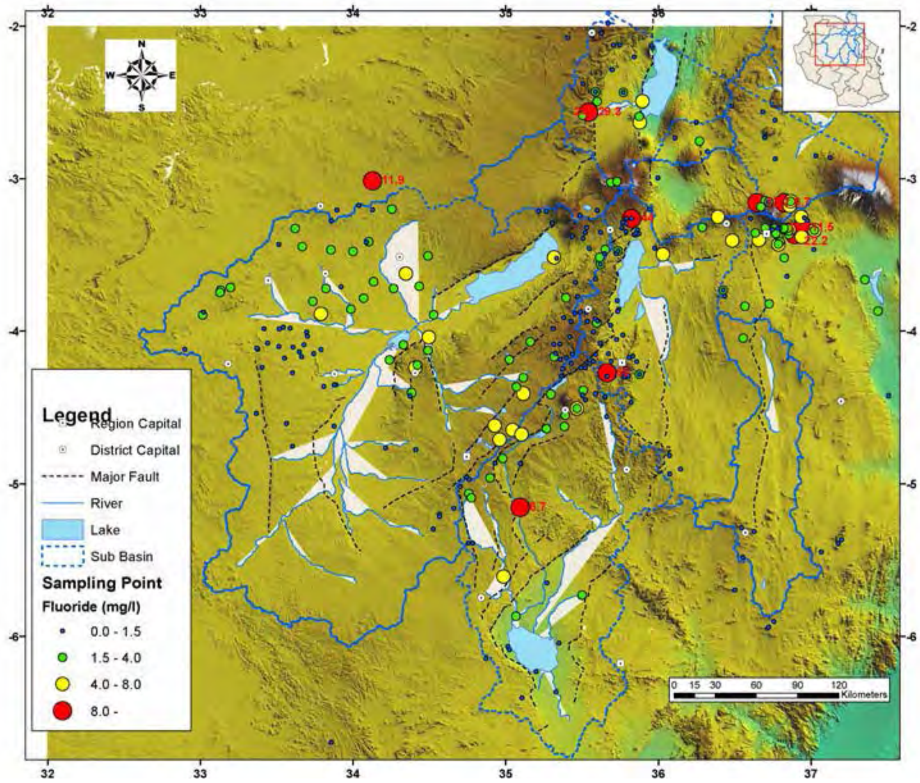


Figure 3-3 Distribution of Fluoride Concentration in Surface Water in IDB

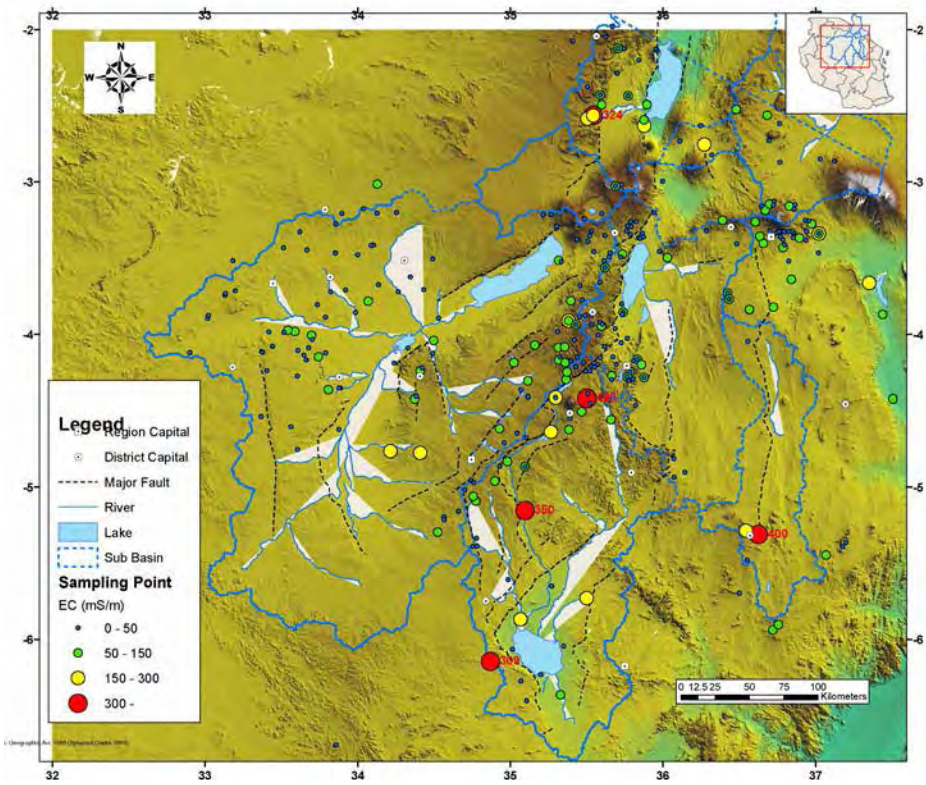
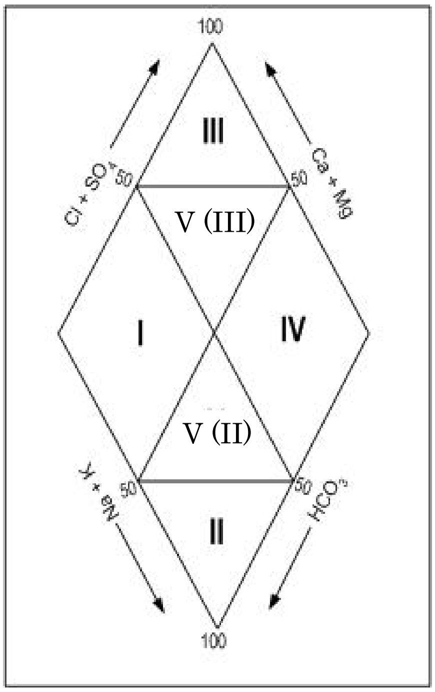


Figure 3-4 Distribution of EC in Surface Water in IDB

Trilinear diagrams of the major components (Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-} SO_4^{2-} and HCO_3^{-}) in surface water were drawn based on analysis results of each water source obtained from the laboratory test in the Study. Figure 3-5 shows the trilinear diagrams for springs as well as for rivers, dams and lakes. Trilinear diagrams were drawn to elucidate quantitative relationships among the major components using equivalent per mole percentage (epm %) and classify water source quality types. Water qualities were generally classified into five types using a conventional diamond-shaped coordinate diagram - known as a “key diagram” - depending on the plotted zone, as shown below. Also, each water sample generally displayed characteristics according to their classification, which are shown below.

Type I: Alkaline earth bicarbonate (Ca $(HCO_3)_2$)
II: Alkaline bicarbonate ($NaHCO_3$)
III: Alkaline earth non-carbonate ($CaSO_4$ or $CaCl_2$)
IV: Alkaline non-carbonate (Na_2SO_4 or NaCl)
V: Intermediate composition (sometimes integrated into Type II and III)



In the case of confined groundwater free of salination, the longer retention time causes the sulfate (SO_4^{2-}) level to decrease through reductive reaction; meanwhile the bicarbonate (HCO_3^{-}) level increases and sodium (Na^{+}) levels fall below calcium (Ca^{2+}) levels due to a base-exchange reaction. This process corresponds to the changes within their plotted zone from Type V(III) through Type I to Type V(II).

The trilinear diagrams of surface water in the Study show that samples from surface water (except springs) containing low fluoride levels fall into the Type I category, while those with higher fluoride levels belong to Type IV. In the case of springs, low fluoride samples also fall into Type I, but the samples with higher fluoride levels belong to Type II or IV. The results indicate that more spring water samples fall into the Type II category compared to other surface water sources, and that longer retention conditions exposes spring water to chemical reactions (such as elution and exchange reaction process from strata) which increases fluoride levels.

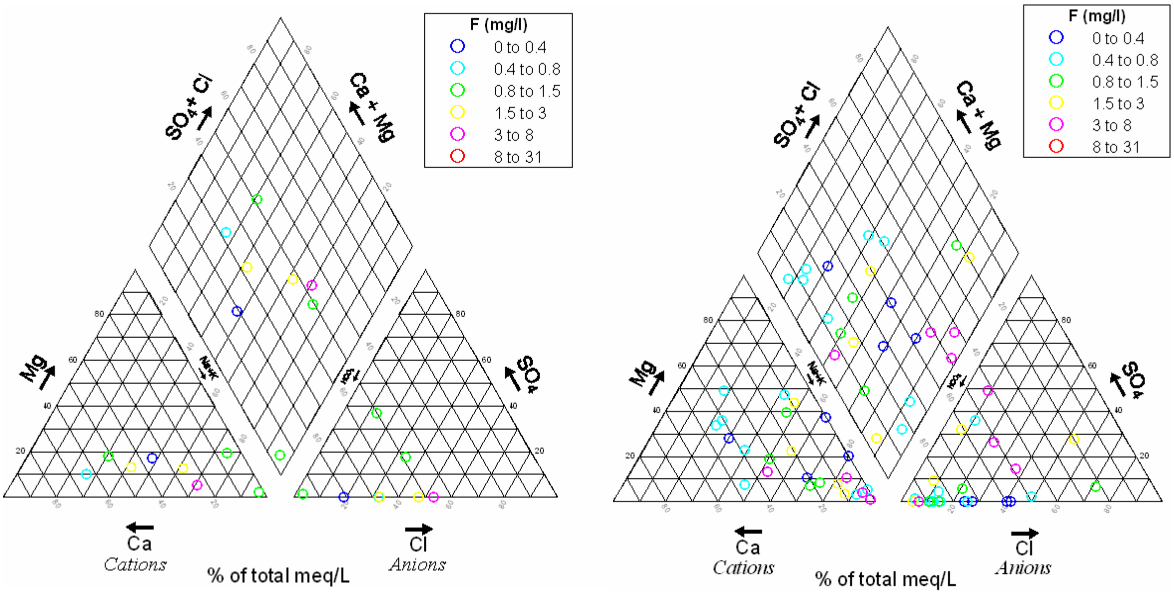


Figure 3-5 Trilinear Diagram of Surface Water in IDB
(Left figure; Dam, Pond and River, Right figure; Spring)

3.3 Groundwater Quality

3.3.1 Shallow Groundwater

Water quality of “dug wells, shallow wells and traditional dug wells (waterholes)” (hereinafter referred to simply as "shallow groundwater") in IDB were analyzed using existing records, simplified water quality tests and the inventory survey for fluoride (F) at 868 locations, electric conductivity at 882 locations, and pH at 258 locations. Table 3-5 shows the concentrations and conditions of occurrence for these parameters for shallow groundwater, and Figure 3-6 and 3-7 show the distribution of fluoride levels (F) and electric conductivity (EC).

The highest average value of fluoride among the six regions was 3.0 mg/l in Arusha Region, followed by 2.0 mg/l in Singida Region. At the local level, a dug well in Esilalei Village, Monduli District in Arusha Region, had the highest concentration of 25 mg/l. Eighteen percent of the shallow groundwater samples exceeded the Tanzanian water quality standard for fluoride in drinking water (fluoride concentration of 4 mg/l or less).

The highest average value of EC among the six regions was 98.7 mS/m in Shinyanga Region, followed by 96.4 mS/m in Dodoma Region. Seventeen percent of the samples exceeded EC levels of 150 mS/m. Singida Region had the highest pH at 7.8. Five percent of the samples had lower pH values than pH 6 and four percent of the samples exceeded pH 9.0.

Table 3-5 Fluoride, EC and pH in Shallow Groundwater in IDB

Region	F (mg/l)				EC (mS/m)				pH			
	No.	Minimum	Maximum	Average	No.	Minimum	Maximum	Average	No.	Minimum	Maximum	Average
Arusha	42	0.2	25.0	3.0	43	7.4	688.0	86.0	43	5.5	8.5	7.0
Manyara	30	0.0	13.3	1.7	29	12.6	205.0	76.7	28	6.3	10.0	7.3
Dodoma	17	0.0	1.1	0.6	17	12.4	305.0	96.4	17	5.6	7.6	7.0
Tabora	38	0.0	5.9	1.2	38	5.5	189.1	49.4	38	5.4	9.5	7.2
Shinyanga	623	0.0	14.0	1.9	622	5.1	302.0	98.7	53	4.8	9.1	7.5
Singida	118	0.1	14.3	2.0	133	6.0	1110.0	92.2	79	3.8	11.0	7.8
IDB	868	0.0	25.0	---	882	5.1	1110.0	---	258	3.8	11.0	---

Fluoride	Dam, Pond and River	
(mg/l)	No.	%
0-0.4	291	34
0.4-0.8	60	7
0.8-1.5	90	10
1.5-4	265	31
4-8	150	17
8-	12	1
Total	868	100

EC	Dam, Pond and River	
(mS/m)	No.	%
0-10	14	2
10-50	178	20
50-150	544	62
150-300	138	16
300-1000	7	1
1000-	1	0
Total	882	100

pH	Dam, Pond and River	
	No.	%
4-5	2	1
5-6	11	4
6-7	72	28
7-8	119	46
8-9	44	17
9-10	10	4
Total	258	100

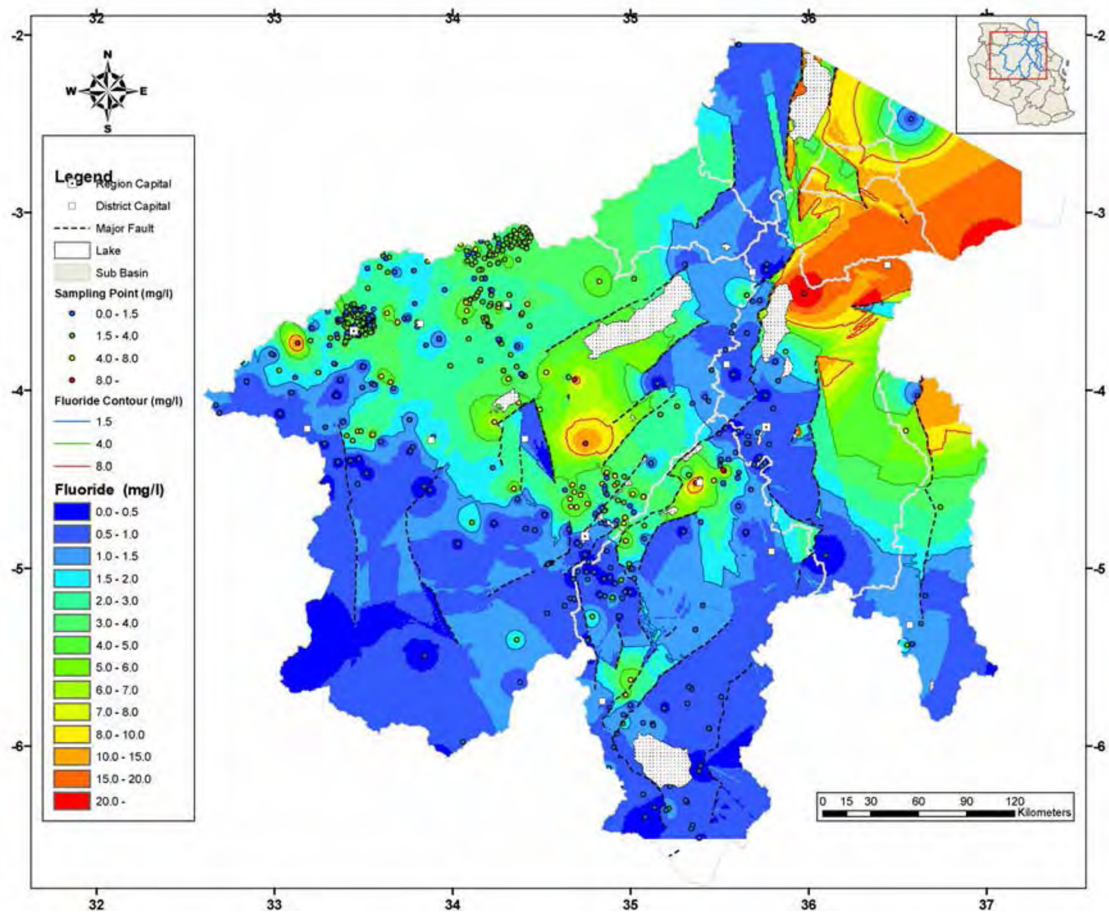


Figure 3-6 Distribution of Fluoride Concentration in Shallow Groundwater in IDB

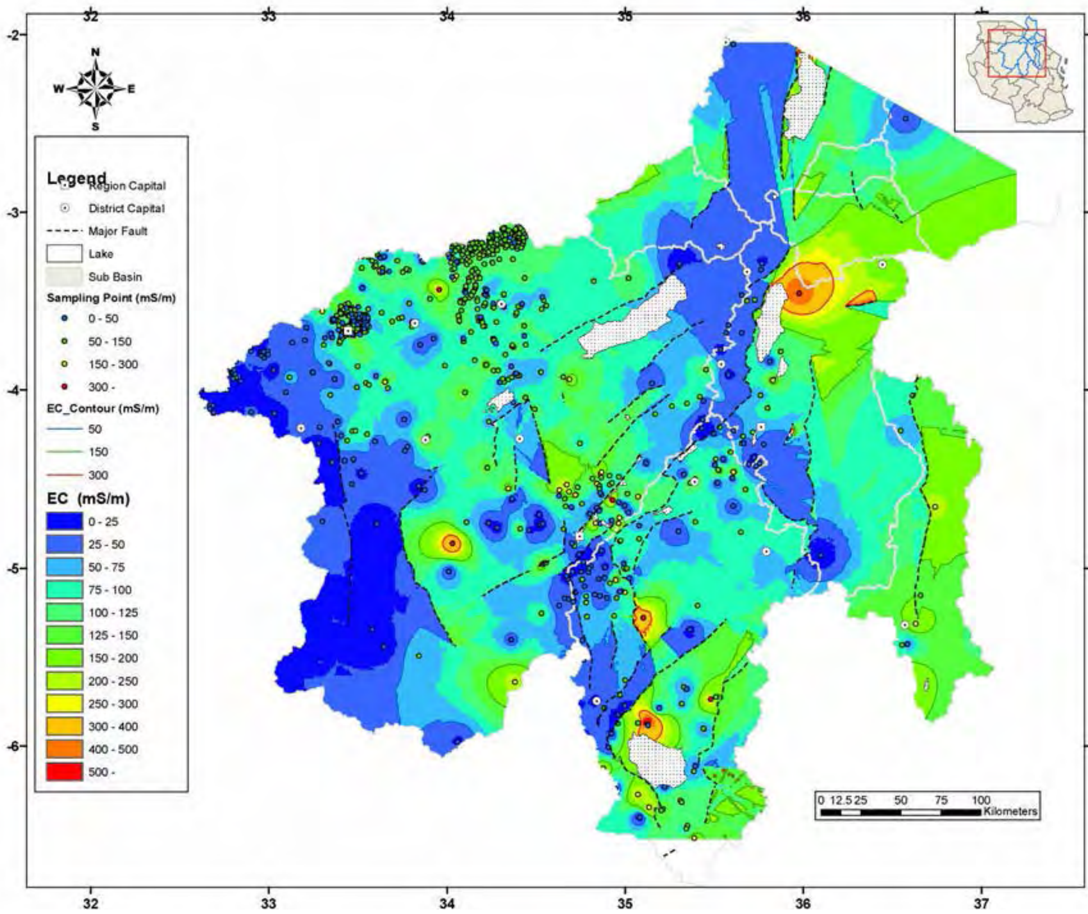


Figure 3-7 Distribution of EC in Shallow Groundwater in IDB

Figure 3-8 shows the trilinear diagram for shallow groundwater. This trilinear diagram reveals that most of the samples of the shallow groundwater in IDB belong to Types II, IV and V(II); Type V(II) meaning an intermediate composition between Types II and IV. In particular, the samples with high fluoride levels tend to belong to Type II, whereas the samples with low fluoride levels tend to belong to Type IV. These facts imply that shallow groundwater with high fluoride levels have similar conditions as spring water in terms of water quality type and the process of fluoride contamination.

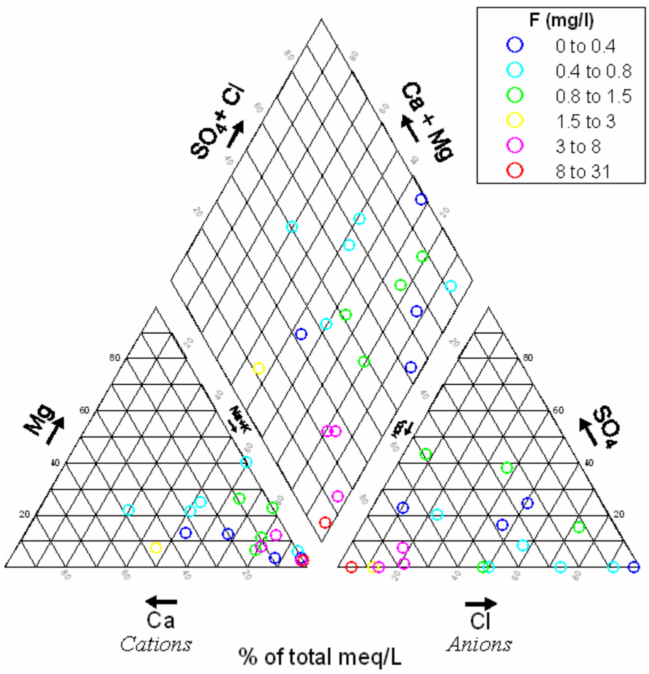


Figure 3-8 Trilinear Diagram of Shallow Groundwater in IDB

3.3.2 Deep Groundwater

Water quality of borehole wells (hereinafter simply referred to as "deep groundwater") in IDB were analyzed using existing records, simplified water quality tests and the inventory survey for fluoride (F) at 386 locations, electric conductivity (EC) at 413 locations, and pH at 382 locations. Table 3-6 shows the concentrations and conditions of occurrence of fluoride (F), electric conductivity (EC) and pH in deep groundwater. Figure 3-9 and 3-10 show the distribution of fluoride concentration and electric conductivity, respectively, of deep groundwater.

Among the six regions, the highest average value of fluoride concentration was 4.1 mg/l in Shinyanga Region, followed by 2.7 mg/l in Arusha Region. At the local level, Ngofila Village, Kishapu District in Shinyanga Region, had the highest concentration of 35 mg/l, followed by that in Piyaya Village, Ngorongoro District in Arusha Region with 31.8 mg/l. Thirteen percent of the samples from borehole wells exceeded the Tanzanian water quality standard of fluoride for drinking water.

Among the six Regions, Shinyanga had the highest EC 166.8 mS/m on average, followed by Singida 134.9 mS/m. Thirty percent of the samples exceeded EC of 150 mS/m. As for pH, the levels were high in Singida and Dodoma (average: pH 7.5). Five percent of the samples were below pH 6 and four percent of the samples exceeded pH 9.

Table 3-6 Fluoride, EC and pH of Deep Groundwater in IDB

Fluoride

Region	Boreholes			
	No.	Minimum	Maximum	Average
Arusha	37	0.2	31.8	2.7
Manyara	50	0.2	7.9	1.2
Dodoma	74	0.0	3.0	1.0
Tabora	28	0.4	7.9	2.1
Shinyanga	39	0.0	35.0	4.1
Singida	158	0.0	15.1	2.3
IDB	386	0.0	35.0	---

Unit: mg/l

Fluoride (mg/l)	Boreholes	
	No.	%
0-0.4	23	6
0.4-0.8	40	10
0.8-1.5	119	31
1.5-4	153	40
4-8	43	11
8-	8	2
Total	386	100

EC

Region	Boreholes			
	No.	Minimum	Maximum	Average
Arusha	38	7.7	903.0	133.7
Manyara	50	17.3	1090.0	145.7
Dodoma	74	16.1	693.0	136.2
Tabora	30	6.8	384.0	122.7
Shinyanga	39	11.9	983.0	166.8
Singida	182	6.1	1190.0	134.9
IDB	413	6.1	1190.0	---

Unit: mS/m

EC (mS/m)	Boreholes	
	No.	%
0-10	7	2
10-50	57	14
50-150	225	54
150-300	98	24
300-1000	17	4
1000-	9	2
Total	413	100

pH

Region	Boreholes			
	No.	Minimum	Maximum	Average
Arusha	38	6.1	9.3	7.4
Manyara	49	6.5	8.7	7.1
Dodoma	64	5.7	8.9	7.5
Tabora	30	6.1	9.2	7.3
Shinyanga	30	5.1	8.8	7.5
Singida	171	4.2	10.5	7.2
IDB	382	4.2	10.5	---

pH	Boreholes	
	No.	%
4-5	2	1
5-6	15	4
6-7	103	27
7-8	225	59
8-9	23	6
9-10	14	4
Total	382	100

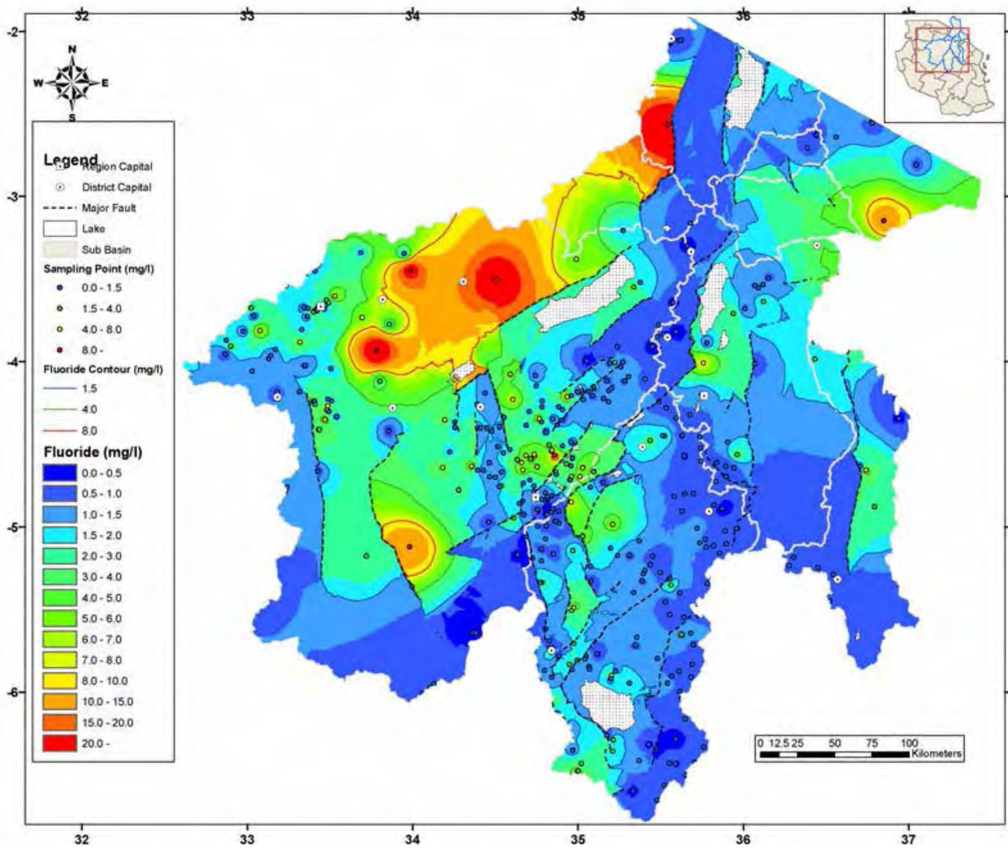


Figure 3-9 Distribution of Fluoride Concentration in Deep Groundwater in IDB

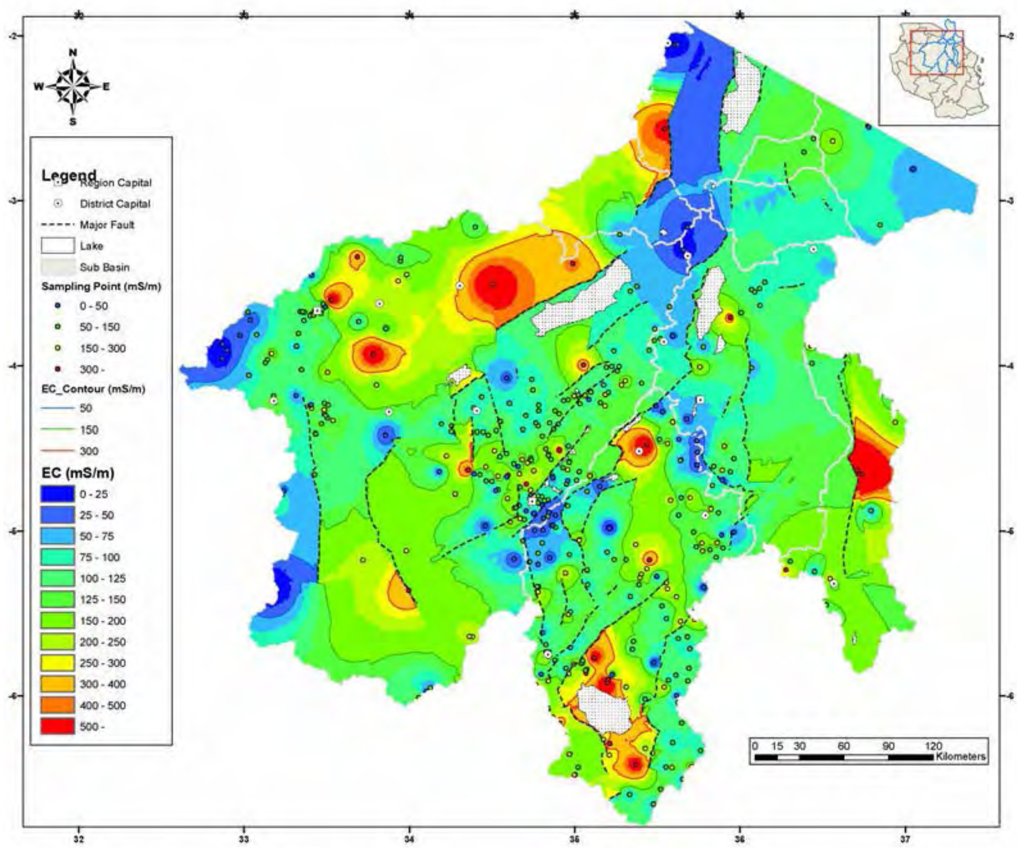


Figure 3-10 Distribution of EC in Deep Groundwater in IDB

Figure 3-11 shows the trilinear diagram for the deep groundwater samples. This diagram reveals that deep groundwater samples in IDB are distributed amongst all types, I to V.

The samples with higher fluoride concentration belong to Type II or IV, as is the case with spring water samples. As such, deep groundwater in IDB is classified into various water quality types, which suggests the existence of a complex groundwater system.

As with spring water and shallow groundwater, deep groundwater distributed in the Type II zone (alkaline bicarbonate) tends to be under longer retention conditions, then exposed to chemical reactions which increase the fluoride concentration through elution and exchange reaction process from strata.

As for the deep groundwater distributed in the Type IV zone (alkaline non-carbonate, NaCl type), it is unclear how fluoride concentration increases, however the origins of fluoride may be alkaline lakes or hot springs which contain high fluoride levels.

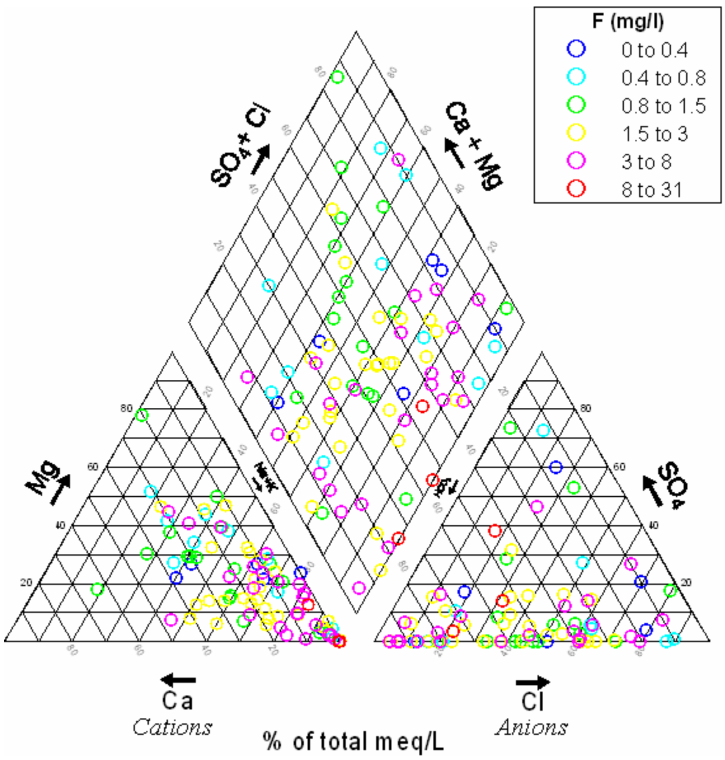


Figure 3-11 Trilinear Diagram of Deep Groundwater in IDB

3.4 Other Relevant Features of Water Quality

3.4.1 Seasonal Changes of Water Quality

Large seasonal changes in water quality between the rainy season and the dry season were expected. Using the results of the inventory survey and the simplified water quality test, data from identical points during the rainy season and dry season were analyzed to clarify the seasonal changes of water quality according to the type of water source. The water quality survey was conducted at a total of 324 points during both the dry and rainy seasons. Table 3-7 shows the regional average value of fluoride concentration (F) and electric conductivity (EC).

The fluoride concentration in the dry season was 1.4 times higher than that in the rainy season on average for all the samples. The largest difference is 4.1 times in Shinyanga Region, followed by 2.8 times in Singida Region. In the case of EC, there was no significant increase; EC during the rainy season was only 1.1 times greater on average than during the dry season. EC was not measured by a Pack Test but using an EC meter.

One of the possible causes for the difference seen between fluoride and EC measurements seems to be the methods of measurement. For every region except Arusha, there were two measurement methods used for fluoride, utilizing a Pack Test for the rainy season and Portable Meters for the dry season. Measurements in Arusha region, on the other hand, were taken using portable fluoride meters in both seasons. The Pack Test applies the colorimetric assay method so that it is difficult to obtain accurate results for high fluoride concentrations. Therefore, there is the possibility that high concentrations of fluoride may have been overlooked during the rainy season since Shinyanga region and Singida region have many water resources with a high concentration of fluoride.

In the Arusha Region, where a portable meter was used for all measurements, none of the water sources showed any significant differences in fluoride concentration between the two seasons.

These facts suggest that the seasonal change of fluoride concentration, as with EC, is slightly higher during the dry season in each water source in IDB.

Table 3-7 Average Value of Fluoride and EC in Rainy and Dry Seasons

Fluoride

Region	Borehole			Dug well, Shallow well, Waterhole			Dam, Pond, River and Rain			Spring			Tatal		
	No.	Rain	Dry	No.	Rain	Dry	No.	Rain	Dry	No.	Rain	Dry	No.	Rain	Dry
Arusha	13	1.4	1.9	2	0.7	**1.8**	12	4.8	4.2	28	2.2	2.1	55	2.5	2.5
Manyara	8	1.5	1.5	16	0.7	0.9	4	1.0	1.5	16	1.0	1.2	44	1.0	1.2
Dodoma	4	0.9	1.1	17	0.7	0.6	2	0.6	0.7	7	1.1	1.2	30	0.8	0.8
Tabora	11	2.0	1.4	14	0.8	0.5	9	0.5	0.8	1	0.4	0.8	35	1.1	0.9
Shinyanga	16	1.9	**5.7**	28	2.7	4.5	23	1.0	**2.8**	4	0.7	**2.1**	71	1.8	**4.1**
Singida	36	1.9	3.4	27	1.0	**2.5**	18	1.2	1.9	8	1.2	1.5	81	1.4	**2.8**
Total	88	1.8	**3.1**	104	1.3	2.2	68	1.6	2.4	64	1.5	1.7	316	1.5	2.4

Over twice of average in rainy season Unit: mg/l

EC

Region	Borehole			Dug well, Shallow well, Waterhole			Dam, Pond, River and Rain			Spring			Tatal		
	No.	Rain	Dry	No.	Rain	Dry	No.	Rain	Dry	No.	Rain	Dry	No.	Rain	Dry
Arusha	13	84.4	82.3	2	46.6	45.0	12	73.1	59.1	28	53.7	53.5	55	64.9	61.3
Manyara	8	247.8	228.2	16	125.1	106.1	4	35.0	30.7	16	67.0	75.7	44	118.1	110.4
Dodoma	4	150.4	169.3	17	108.0	96.4	2	33.8	37.0	7	113.6	111.1	30	110.0	105.6
Tabora	11	66.4	98.9	14	39.9	31.2	9	22.6	42.8	1	41.5	33.8	35	43.9	55.5
Shinyanga	16	95.7	124.3	28	88.1	61.1	23	19.4	31.0	4	36.5	13.3	71	64.6	62.9
Singida	35	130.1	141.2	27	38.0	**121.7**	18	37.5	54.4	8	54.0	59.2	80	78.2	115.4
Total	87	120.6	133.2	104	76.8	85.2	68	35.4	43.9	64	62.3	63.2	315	77.6	85.8

Over twice of average in rainy season Unit: mS/m

3.4.2 Water Pollution

In IDB, there are many areas whose water is contaminated not only by fluoride, but also nitrate, iron, coliform bacteria and such, with values that exceed Tanzanian standards and/or the WHO guidelines. However, the actual conditions of such water pollution have not yet been fully understood. Thus, in order to clarify actual water pollution in IDB, a water quality survey was carried out using simplified water quality tests and laboratory tests.

(1) Nitrate, Ammonium, Iron, Manganese and Coliform Bacteria

Table 3-8 shows the concentrations of nitrate (NO_3^-), ammonium (NH_4^+), iron (Fe), manganese (Mn) and coliform bacteria as they occur at each water source in IDB.

It is generally considered that contamination by human and livestock excreta causes an increase in nitrate concentrations. A high nitrate concentration of 40 mg/l or above was measured most frequently at dug wells (12 ~ 13 % of 104 points in both seasons), followed by boreholes (7 ~ 8 % of 88 points).

Similar to nitrate, contamination by the excreta of humans and livestock causes an increase of ammonium concentration. A high ammonium concentration of 2 mg/l (the Tanzanian standard for drinking water) or above was frequently found in rivers, dams and ponds (8 ~ 16 %), followed by dug wells (7 ~ 8 %).

A high iron concentration of 1 mg/l (the Tanzanian standard for drinking water) or above was measured most frequently at dug wells (2 ~ 8 %). It was also measured at other water sources (2 ~ 5 %).

A high manganese concentration of 0.5 mg/l (the Tanzanian standard for drinking water) or above was measured most frequently at boreholes (13 ~ 22 %), also at rivers, dams and ponds (16 ~ 21 %).

Twenty two to 52 % of all the water sources were excessively contaminated with coliform bacteria; even 7 ~ 15 % of boreholes were excessively contaminated with this bacteria.

Table 3-8 NO_3, NH_4, Fe, Mn and Coliform Bacteria in IDB

Items	Range (mg/l)	Rainy Season								Dry Season							
		Borehole		Dug well,		Dam, Pond, River		Spring		Borehole		Dug well,		Dam, Pond, River		Spring	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
NO3	0-1	17	19	22	21	11	17	11	17	12	14	24	23	17	25	11	17
	1-5	28	32	24	23	37	57	36	56	41	47	48	46	31	46	36	56
	5-10	11	13	14	13	7	11	7	11	8	9	6	6	3	4	8	13
	10-20	13	15	19	18	4	6	2	3	11	13	12	12	14	21	5	8
	20-40	13	15	12	12	4	6	5	8	9	10	2	2	0	0	1	2
	40-50	6	7	13	13	2	3	3	5	7	8	12	12	2	3	3	5
	Total	88	100	104	100	65	100	64	100	88	100	104	100	67	100	64	100
NH4	0-0.3	60	68	48	46	37	57	50	78	77	88	66	63	47	70	47	73
	0.3-0.6	25	28	32	31	17	26	7	11	7	8	24	23	8	12	12	19
	0.6-1.1	2	2	14	13	6	9	5	8	2	2	5	5	1	1	2	3
	1.1-2	0	0	1	1	0	0	0	0	1	1	1	1	0	0	0	0
	2-5	0	0	8	8	5	8	2	3	1	1	7	7	11	16	2	3
	5-20	1	1	1	1	0	0	0	0	0	0	1	1	0	0	1	2
	Total	88	100	104	100	65	100	64	100	88	100	104	100	67	100	64	100
Fe	0-0.06	74	84	76	73	51	78	52	80	76	86	87	84	55	82	55	86
	0.06-0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.1-0.3	3	3	10	10	5	8	6	9	5	6	7	7	6	9	3	5
	0.3-0.5	3	3	7	7	5	8	3	5	2	2	4	4	4	6	3	5
	0.5-1	6	7	3	3	2	3	1	2	2	2	4	4	0	0	1	2
	1-3	2	2	8	8	2	3	3	5	3	3	2	2	2	3	2	3
	Total	88	100	104	100	65	100	65	100	88	100	104	100	67	100	64	100
Mn	0-0.5	77	88	89	86	55	85	34	53	68	77	93	89	53	79	34	53
	0.5-1	11	13	6	6	9	14	26	41	18	20	4	4	14	21	29	45
	1-2	0	0	5	5	1	2	2	3	2	2	2	2	0	0	1	2
	2-5	0	0	2	2	0	0	2	3	0	0	3	3	0	0	0	0
	5-10	0	0	2	2	0	0	0	0	0	0	2	2	0	0	0	0
	Total	88	100	104	100	65	100	64	100	88	100	104	100	67	100	64	100
Coliform*	N.C	47	57	14	15	6	10	32	50	65	74	32	31	18	27	15	23
	S.C	23	28	32	34	26	41	18	28	17	19	37	36	16	24	19	30
	E.C	12	15	49	52	31	49	14	22	6	7	35	34	33	49	30	47
	Total	82	100	95	100	63	100	64	100	88	100	104	100	67	100	64	100

Coliform: N.C (Not Contaminated), S.C (Slightly Contaminated), E.C (Extremely Contaminated)

Figure 3-12 shows distribution of the concentrations of nitrate (NO_3^-), ammonium (NH_4^+), iron (Fe), manganese (Mn) in IDB in the dry season.

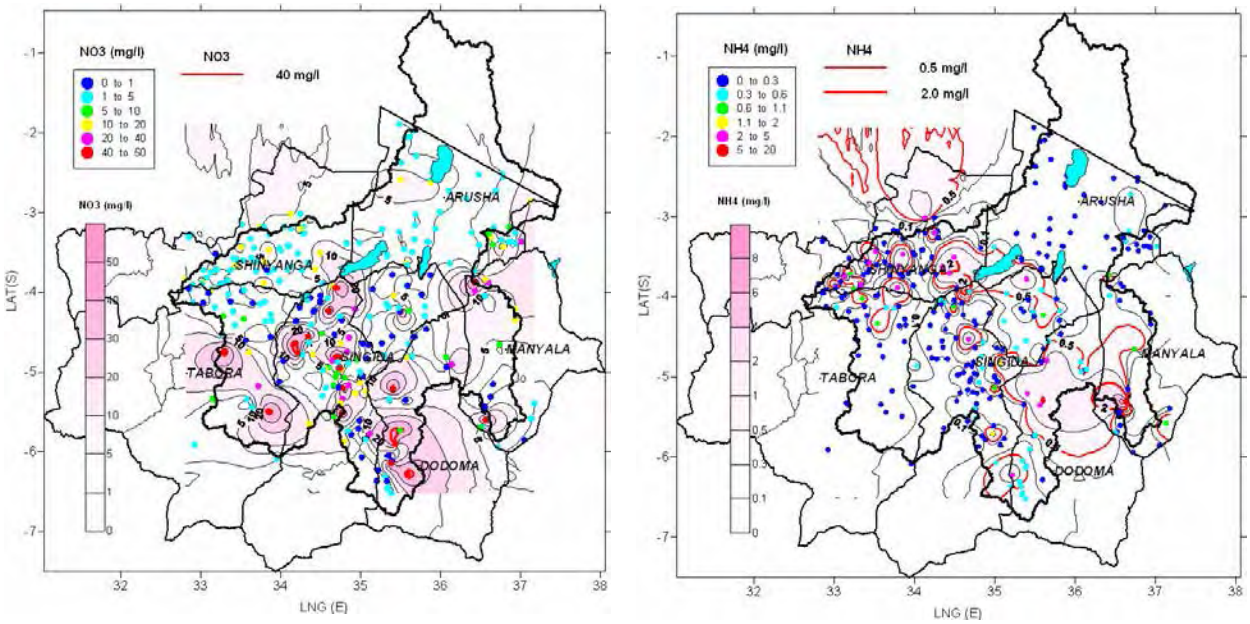


Figure 3-12(1) Distribution of NO_3 and NH_4 in Dry Season in IDB

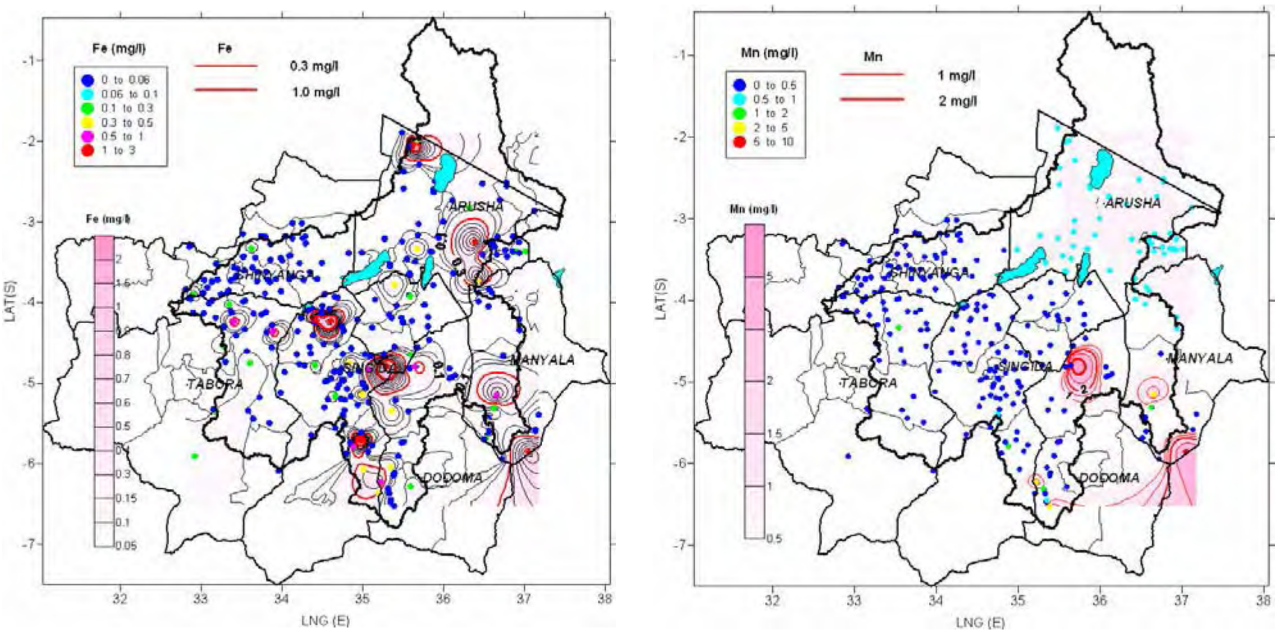


Figure 3-12(2) Distribution of Fe and Mn in Dry Season in IDB

3.4.3 Hazardous Materials

Water sources in IDB were analyzed in a laboratory test to assess compliance with the Tanzanian standards and WHO Guidelines for health hazards (hazardous materials) and those for drinking and household water. Figure 3-13 shows the result of the compliance assessment of the samples taken from the existing water sources in the Study.

The heavy metal hexavalent chromium (Cr (VI)), considered a human health risk, exceeded the Tanzanian and WHO standards in one out of a total of 139 samples, and barium (Ba) exceeded these standards in 4.3 % of all samples. While no zinc (Zn) samples exceeded the Tanzanian standard, three zinc (Zn) samples (2.2 %) exceeded the WHO standard (guideline value).

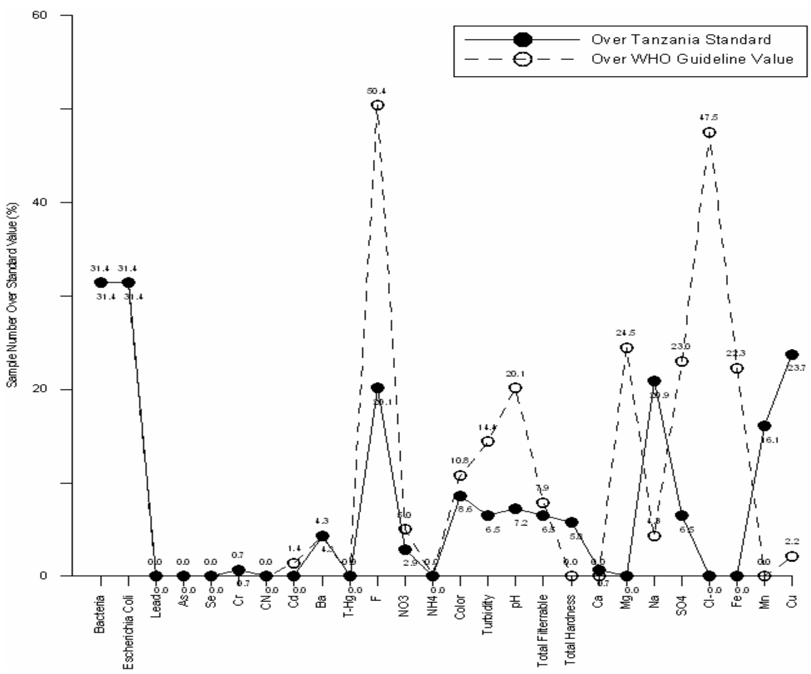


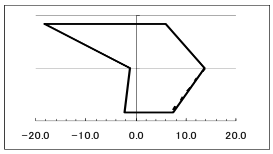
Figure 3-13 Compliance Assessment to the Standards for Drinking Water

3.4.4 Relationship between Fluoride and Other Water Quality Items

Some of the fluoride-rich water sources belong to Type II (alkaline bicarbonate type) whereas others belong to Type IV (alkaline non-carbonate / NaCl-type) in the trilinear diagram as mentioned in 3.2.2. With the aim of clarifying the supply sources of fluoride to water sources and the mechanism for the increase in concentration, hexa diagrams of the major components of the water sources (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, $SO_4^{2-}$and HCO_3^-) were drawn and used in the analysis. To create a hexa diagram, the cations and the anions are plotted on the left and right sides respectively, and the points representing the cations and anions are joined with straight lines. The shape of the diagram is used for classification of groundwater systems and analysis of changes in water quality caused by movement of groundwater. A wide diagram indicates high concentrations of these components and a narrow diagram indicates low concentrations.

Figure 3-16 shows the hexa diagram for all the samples in IDB. Figure 3-17 shows the hexa diagram for sub-basin A, which has a relatively large number of fluoride-rich water sources. The points with high fluoride concentrations are found in Karatu, Arumeru and Ngorongoro Districts in Arusha Region, Hanang and Simanjiro Districts in Manyara Region, Igunga District in Tabora Region, Meatu and Kishapu Districts in Shinyanga Region and Manyoni and Singida Rural Districts in Singida Region. These points are located in the areas of volcanic rocks with high fluoride concentration, and the surrounding areas are dotted with alkaline (NaCl-type) lakes with high fluoride concentration.

A hexa diagram like the one shown in the figure on the right was obtained at many of the water sources with the fluoride concentration of 8 mg/l or above. The shape of this diagram indicates high concentrations of sodium (Na^+) and potassium (K^+) and low concentrations of calcium (Ca^{2+}) among the cations, and high concentrations of bicarbonate (HCO_3^-) and low concentrations of chloride (Cl^-) among the anions.



In addition to diagrams like the one shown on the right, diagrams featuring a wide reverse-triangular shape were obtained at a significant number of water sources with a fluoride concentration of less than 8 mg/l. The shape of this diagram indicates that the concentrations of sodium (Na^+) and chloride (Cl^-) are the highest among the cations and the anions, respectively. In the southern part of IDB, some water sources gave one of the two types of hexa diagrams. However, since the fluoride concentration at these water sources is relatively low, it is suggested that there are few supply sources of fluoride that have high fluoride concentration like those mentioned earlier in this section.

The results of the analyses with hexa diagrams and above-mentioned trilinear diagrams reveal that some of the fluoride-rich water sources in IDB have a high concentration of alkaline bicarbonate ($NaHCO_3$), whereas others are rich in alkaline non-carbonate (NaCl). In addition to that, water sources characterized as alkaline bicarbonate ($NaHCO_3$) tend to have a higher fluoride concentration than those characterized as alkaline non-carbonate (NaCl). Gunnar Jacks and others (2005) reported the mechanism that increased fluoride concentration in the alkaline bicarbonate ($NaHCO_3$) type groundwater and explains that high fluoride concentration of groundwater in South India is closely related to the decrease of calcium (Ca) and magnesium (Mg), and an increase of sodium (Na) and bicarbonate (HCO_3^-). Calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$), such as carbonate minerals, release bicarbonate (HCO_3^-) through weathering. From the relationship among these water quality parameters (calcium (Ca), magnesium (Mg), sodium (Na) and bicarbonate (HCO_3^-)) and fluoride (F^-), it is believed that the enrichment of fluoride (F^-) in the groundwater takes place through the weathering of minerals with high fluoride and the precipitation of carbonate minerals via evapotranspiration, as shown in Figure 3-14.

From the above-mentioned results, the infiltration effect of fluoride into groundwater from alkaline lakes or hot springs, as well as elution from the volcanic strata, is considered as a possible supply source of fluoride to the water sources in IDB. Groundwater is more likely to be affected by elution of fluoride from strata in the area where it is retained for an extended period. In addition to the elution, evapotranspiration and exchange reaction with carbonated minerals are considered as possible causes of extremely high fluoride concentrations in the groundwater of IDB.

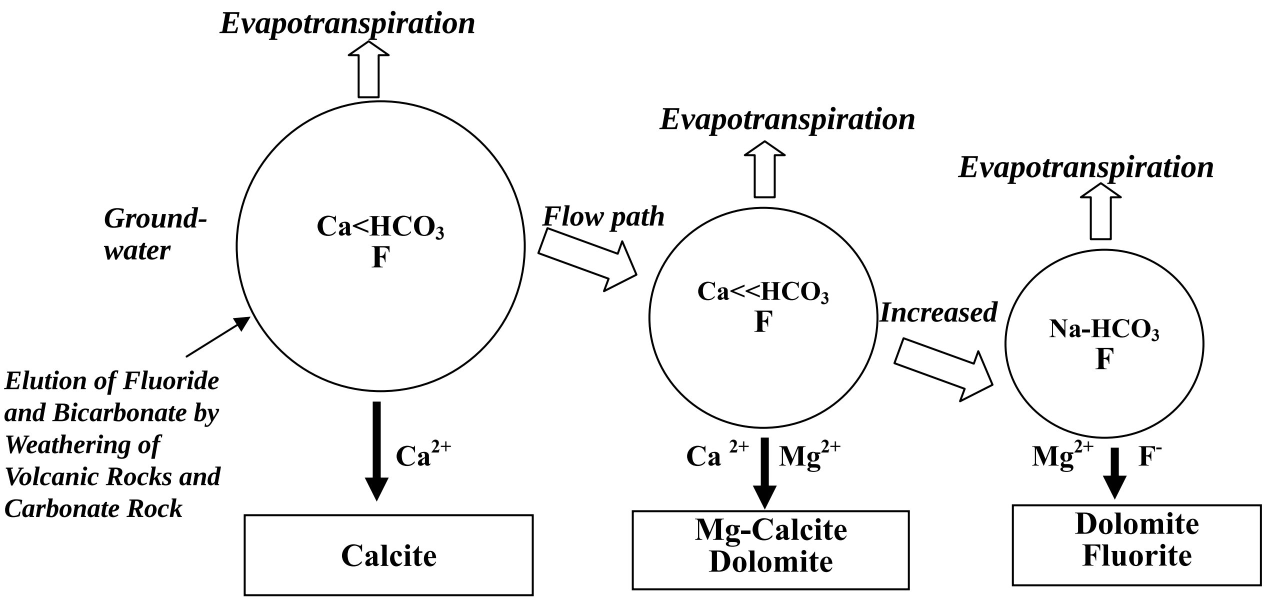


Figure 3-14 Mechanism of Formation of High Fluoride Groundwater in South India

(Source: Gunner Jacks et al (2005) "Controls on the genesis of some high-Fluoride Groundwater in India")

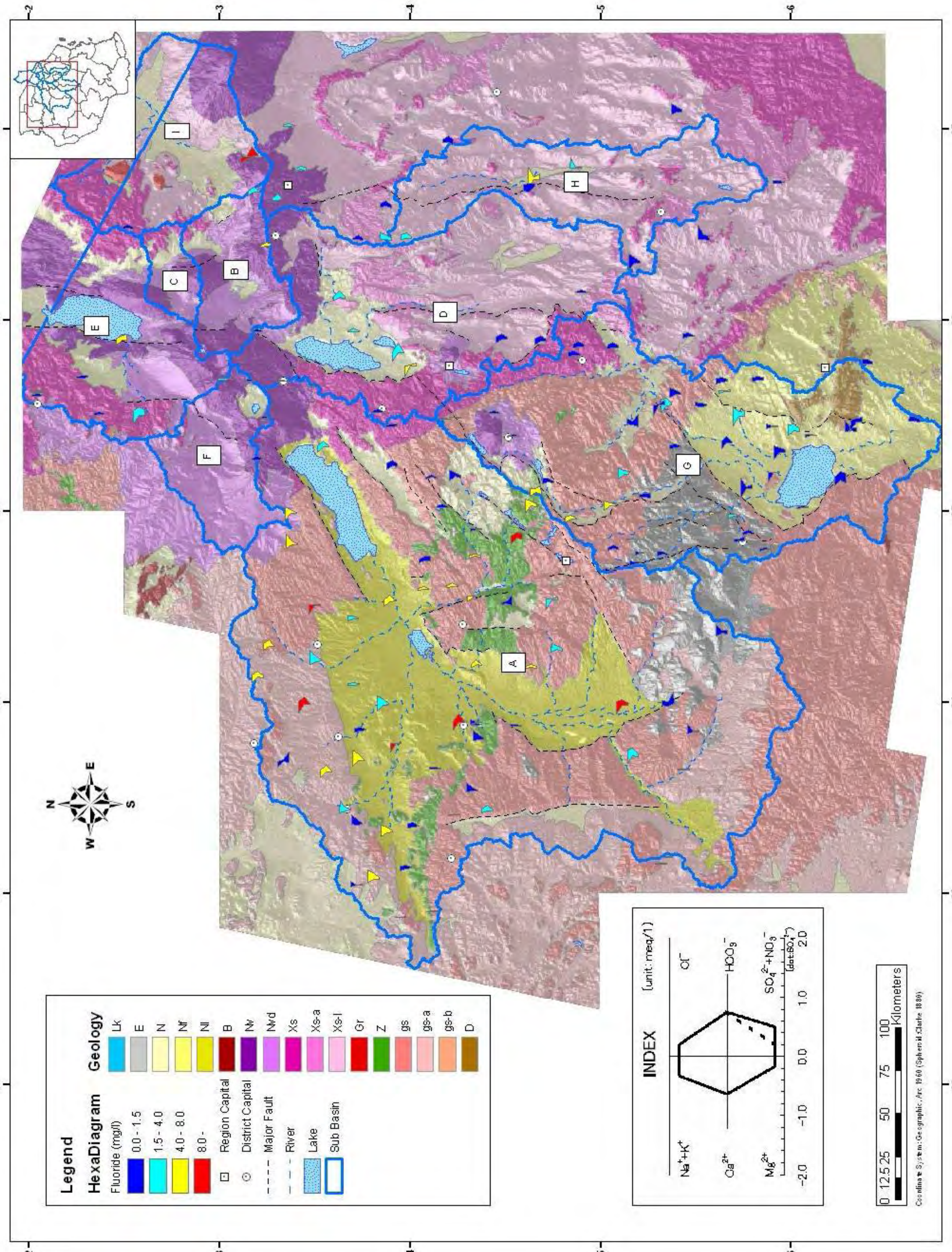


Figure 3-15 Hexa Diagram in Existing Water Sources throughout the Basin

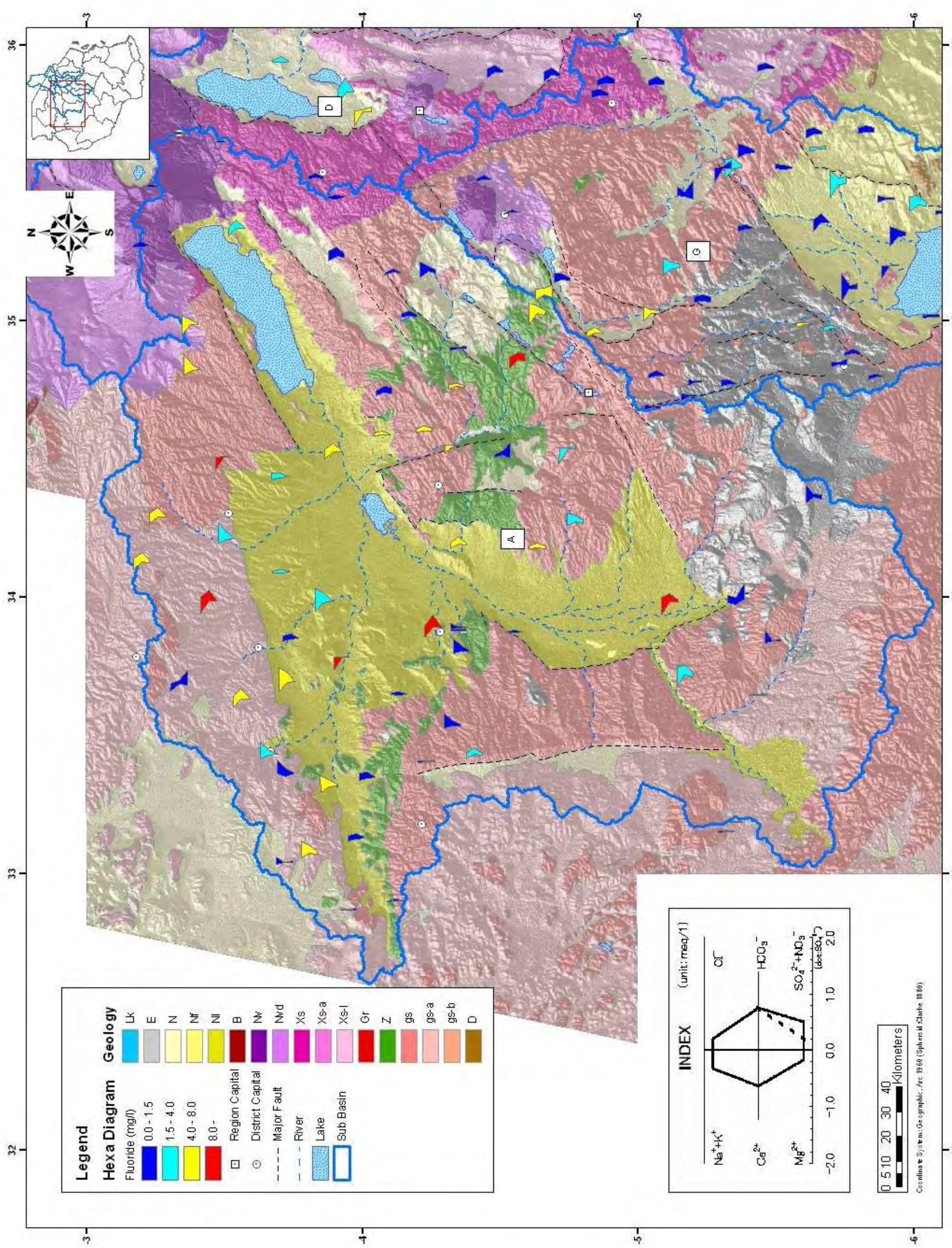


Figure 3-16 Hexa Diagram in Existing Water Sources in the Sub-basin A

3.5 Fluorosis and Water-related Diseases

3.5.1 Consciousness of Fluorosis and Water-related Diseases

A survey of villager awareness of fluorosis and water-related diseases in IDB was included in the socio-economic survey conducted through questionnaires and interviews. (Refer to Chapter 10 of the Supporting Report)

(1) Affected Condition of Main Water-related Disease and Awareness of Sickness

Since the villagers in IDB use contaminated water sources on a daily basis, such as traditional dug wells, puddles created by rainwater, ponds and lakes, they are faced with water-related diseases, such as diarrhoea, typhoid, skin disease and eye disease. Major water-related diseases are diarrhoea (41 %), typhoid (34 %) and eye disease (11 %) as shown in Figure 3-17. The occurrence of these diseases is higher in the rainy season than the dry season because villagers tend to fetch water from convenient, yet contaminated water sources.

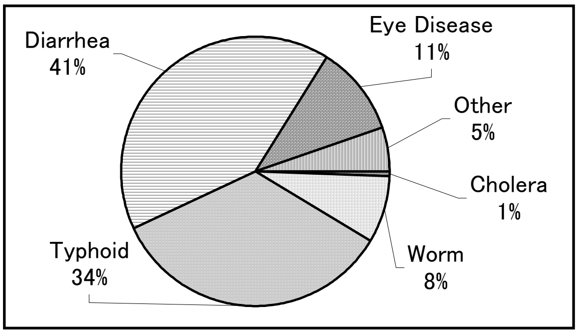


Figure 3-17 Domestic Water-related Diseases

According to the household survey, 73 % of villagers understand the cause of water-related diseases, and most of them answered that safe water or hygienic living conditions would prevent disease (Refer to Figure 3-18). However, only 27 % of residents boiled water and 63 % of residents drink water directly from water sources without treatment as shown in Figure 3-19.

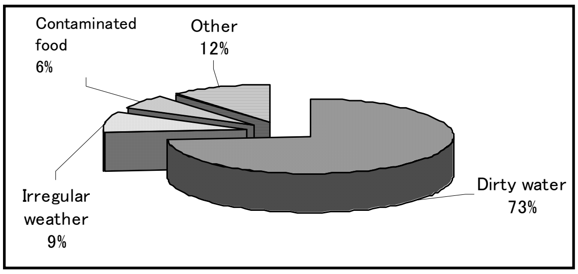


Figure 3-18 Cause of Water-related Diseases

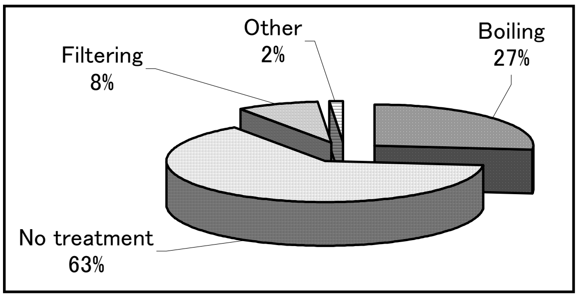


Figure 3-19 Pre-drinking Water Treatment

(2) Fluorosis

1) Villager Awareness

According to the village survey, 56 % of village leaders are conscious of fluorosis; however, 67 % of villagers are not. (Refer to Figure 3-20).

2) Overview of the Problem

In the interviews of the dental fluorosis survey, more than half of the respondents answered that the symptom of brown teeth was evident in their village or family. Since they understand the cause of fluorosis, they tried to use different water sources for drinking and other purposes. However, some villages have no alternative water sources.

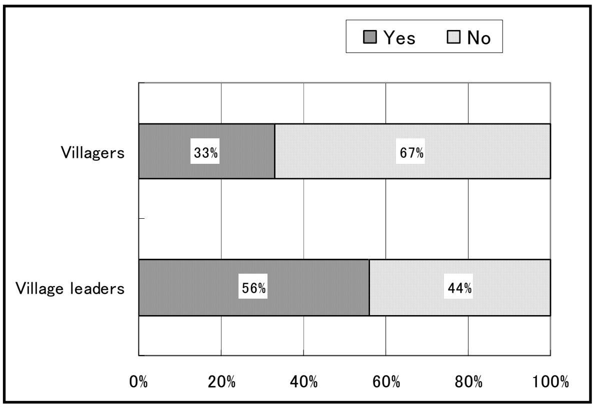


Figure 3-20 Consciousness of Fluorosis

3) Using Condition of Magadi (Torona)

It is said that a local rock salt called "Magadi" is one of the main causes of fluorosis in Tanzania. Most villagers in IDB use Magadi; however, the household survey revealed that they do not know Magadi contains a high level of fluoride. The villagers are accustomed to use Magadi mainly for cooking a traditional vegetable dish called "Murenda" to reduce cooking time. Magadi is mainly collected from lakes and swamps within IDB and the neighbouring areas. The cause of fluorosis in IDB seems to be not only water but also Magadi.

3.5.2 Health Effects of Fluoride

The fluoride contained in drinking water contributes significantly to the daily fluoride intake. Increasing fluoride content in drinking water, up to about 1 mg/L is known to prevent dental caries. Higher concentrations, however, are harmful and cause fluorosis as shown in Table 3-9. Chronic fluoride toxicity induces early decalcification of tendons, ligaments and joint capsules especially in the vertebral column (Teri, 1982 in Mjengera, 1988). The clinical symptoms of skeletal fluorosis are bowlegs and knocked-knees (genu valgum), stiffness of the trunk, impeded movement of the limbs and severe joint contractions, referred to as crippling fluorosis (Nanyaro et al., 1984).

A recent study by Eliuze (2004) reported cases of fluorosis in different age groups in Maji ya Chai village in Arusha. The study indicated that people aged between 18 and 27 years were the most susceptible to fluorosis, whereas those aged above 57 years were the least affected (Refer to Figure 3-22). Table 3-10 shows occurrence of fluorosis in school children in Maji ya Chai Village in Arusha region expressed in terms of Dean Index.

Table 3-9 Categories of Fluorosis

Fluoride Concentration of Drinking Water (mg/L)	**Likely Disease**	**Symptoms**
1.5 – 3	Dental Fluorosis	Objectionable mottling of the teeth
4 – 8	Skeletal Fluorosis	Malformation of the bones; Movement difficulties
> 10	Crippling Fluorosis	Bone functions growing together; Immobility

Source: WHO, 1994

Figure 3-21 Symptoms of Crippling Fluorosis (Eliuza, 2004)

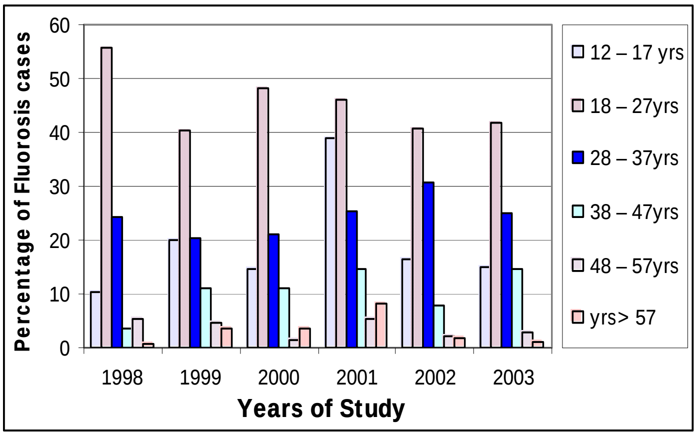


Figure 3-22 Percentage Distribution of Fluorosis Cases among Age Groups in Maji ya Chai Village, Arusha Region (Eliuza, 2004)

Table 3-10 Occurrence of Fluorosis in School Children in Maji ya Chai Ward in Arusha Region

Name of School	Fluoride (mg/L)	Total Number of Pupils	Scores												
			Normal		Trace		Very mild		Mild		Moderate		Severe		Mean CFI*
			0		0.5		1		2		3		4		
			No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	
Embaseni	2.8	96	0	0	0	0	0	0	12	13	41	43	43	45	3.32
Ngurdoto	8.5	43	0	0	0	0	0	0	3	7	8	19	32	74	3.67
Kitefu	2.95	120	0	0	9	7.5	15	13	54	45	31	26	11	9.2	2.2
Nkoanekol	1.7	50	0	0	3	6	22	44	25	50	0	0	0	0	1.47

*CFI: Community Fluorosis Index

(Expressed in terms of Dean Index (modified from Eliuze, 2004)

3.5.3 Fluoride Removal Techniques

Removal hereby refers to the total effects of all possible mechanisms that remove or reduce fluoride in treated water. In one word, the removal of fluoride is defluoridation. The technology of defluoridation has been well developed and tested to some extent. Research on the technology, experimental work and application of the techniques for excess fluoride removal has been carried out in various parts of the world.

The trial methods of fluoride removal include many factors that must be considered prior to being accepted as the most appropriate methods to be adopted. Some of these methods are efficient, but they are expensive and complex, which means that they would not be the best choice for a developing country. It is difficult to give exact figures in cost analysis of various methods because of the variable factors governing treatment costs for each project. Below is a comparison of three kinds of treatment methods.

Table 3 -11 Comparison of Treatment Methods

No	Method	Working principle	Fluoride removal range	Treatment cost	Matters to be solved for the application
1	Activated alumina	Adsorption with activated alumina	1000 -9600 mgF/L of media	About 22.7 kg of activated alumina costs $ 94.5*	Expensive and relatively complex
2	Bone char	Adsorption	Up to 94 %	Relatively low	Problem of removing the colour formed in the treatment process. Availability of bones in large quantities has to be considered.
3	Electrodialysis	Distillation	7.0 mg F/L to 1.4 mg F/L	Expensive depending on the plant size	A complicated process.

3.5.4 Measures of Fluoride Removal by Other Donors, NGOs and International Organizations

Besides Ministry of Water has already funded Ngurdoto Defluoridation Research Centre in Arusha, however, there are no donors, NGOs or international organizations involved in activities pertaining to defluoridation of water in Tanzania at present.

3.5.5 Water-related Diseases

While water-related diseases vary substantially in their nature, transmission, effects, and management, adverse health effects related to water may be organized into four categories:

- Water-borne diseases; (e.g. Cholera, Typhoid, Shigellosis, Polio)
- Water-washed (scarce) diseases; (e.g. Trachoma, Skin diseases, Leprosy)
- Water-based diseases; (e.g. Guinea worm, Schistosomiasis, Paragonimiasis)
- Water-related vector diseases; (e.g. Malaria, Yellow fever, Dengue fever, Sleeping sickness)

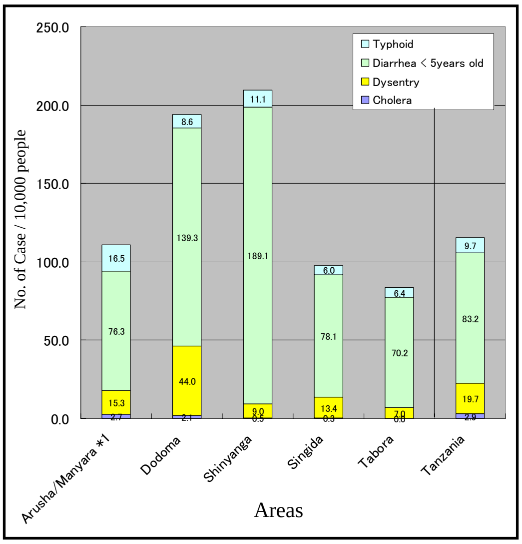


Figure 3-23 Present Conditions of Water-borne Diseases in IDB
(No. of Case / 10,000 people in 2003. Data Source: Ministry of Health)

Present conditions of water-borne diseases in IDB are shown in Figure 3-23. The figure reveals that Shinyanga and Dodoma Regions have a high ratio of water-borne disease incidence.

3.5.6 Dental Fluorosis Survey in IDB

(1) Purpose of Survey

The purpose of the dental fluorosis survey is to determine the prevalence and severity of dental fluorosis and community psychosocial factors related to fluorotic teeth in IDB.

(2) Contents of Survey

The survey was conducted from July to September 2007 involving 2,912 adolescents as examinees aged 12 to 18 years who were born and have lived their entire life in the target villages. Each survey participant was examined for dental fluorosis. Target villages for the survey in 18 districts of IDB were chosen based on water fluoride levels higher than 1.5 mg/l. From these, 96 villages were randomly selected as shown in Figure 3-27. In each village, one school was chosen at random. In each school, 15 boys and 15 girls aged 12-18 years old, who were born and lived in the selected village were picked by quota sampling.

Dental fluorosis was diagnosed and scored using the Thylstrup and Fejerskov Index (TFI) as shown in Table 3-12. Thereafter the adolescents were interviewed about their knowledge on the causes of dental fluorosis and on the psychosocial factors linked to dental fluorosis using questionnaires with structured and open-ended questions. The survey instruments had already been field tested with acceptable levels of validity and reliability.

Water samples and Magadi were collected and analyzed; thereafter the fluoride concentration results were incorporated into the data file for this survey in order to assess the association of fluoride concentration and dental fluorosis.

Table 3-12 Thylstrup and Fejerskov Index – Diagnostic Criteria for Dental Fluorosis Scores

Score			Criteria
Better ↑	Sound	**0**	Normal translucency of enamel remains after prolonged air-drying.
	Questionable	**1**	Narrow white lines corresponding to the perikymata.
	Very Mild	**2**	Smooth surfaces: More pronounced lines of opacity that follow the perikymata. Occasionally confluence of adjacent lines. Occlusal surfaces: Scattered areas of opacity < 2 mm in diameter and pronounced opacity of cuspal ridges.
		3	Smooth surfaces: Merging and irregular cloudy areas of opacity. Accentuated drawing of perikymata often visible between opacities. Occlusal surfaces: Confluent areas of marked opacity. Worn areas appear almost normal but usually circumscribed by a rim of opaque enamel.
	Moderate	**4**	Smooth surfaces: The entire surface exhibits marked opacity or appears chalky white. Parts of surface exposed to attrition appear less affected. Occlusal surfaces: Entire surface exhibits marked opacity. Attrition is often pronounced shortly after eruption.
	Severe	**5**	Smooth surfaces and occlusal surfaces: Entire surface displays marked opacity with focal loss of outermost enamel (pits) < 2 mm in diameter.
		6	Smooth surfaces: Pits are regularly arranged in horizontal bands < 2 mm in vertical extension. Occlusal surfaces: Confluent areas < 3 mm in diameter exhibits loss of enamel. Marked attrition.
		7	Smooth surfaces: Loss of outermost enamel in irregular areas involving < ½ of entire surface.Occlusal surfaces: Changes in the morphology caused by merging pits and marked attrition.
		8	Smooth surfaces and occlusal surfaces: Loss of outermost enamel involving > ½ of surface.
↓ Worse		**9**	Smooth surfaces and occlusal surfaces: Loss of main part of enamel with change in anatomic appearance of surface. Cervical rim of almost unaffected enamel is often noted.

Source: Thylstrup and Fejerskov, 1978. As reproduced in "Health Effects of Ingested Fluoride". National Academy of Sciences, 1993; pp. 171

(3) Survey Result

The prevalence of dental fluorosis was 96.3 %, with the majority of examinees' teeth scoring between TFI 3 and TFI 7. Exploration of the data further revealed that 85.4 % of the examinees had at least one tooth with a TFI score of greater than or equal to TFI 4, as shown in Figure 3-24. Table 3-13 shows the overall mean of TFI for the six regions together is 3.4. The mean TFI score did not vary by age or sex. Arusha had the highest mean TFI score (4.3) followed by Shinyanga (3.5), Singida (3.4), Manyara (3.3), Tabora (2.8) and Dodoma (1.8). On the other hand, the mean TFI of each district is shown in Figure 3-25. Arumeru district had the highest TFI score (4.8) followed by Manyoni (4.2), and Meatu (4.1). Minimum levels were recorded in Singida district- urban (1.4) and Kondoa (1.5). TFI score analysis by village revealed that Kolandoto village in Shinyanga had the highest mean TFI score of 5.2, followed by Olkungwado village in Arusha with a score of 4.9, and Lemong'o (4.8). The lowest mean TFI score (0.4) was recorded at Iyumbu village in Singida region.

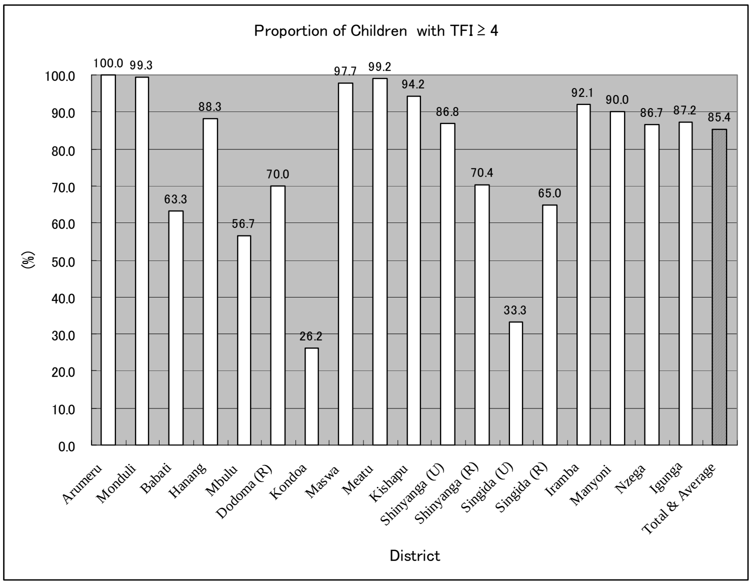


Figure 3-24 Proportion of Children with TFI ≥4

Table 3-13 Mean TFI of each Region

Region	No. of Children	Average TFI
Arusha	150	**4.3**
Dodoma	91	**1.8**
Manyara	330	**3.3**
Shinyanga	1,245	**3.5**
Singida	941	**3.4**
Tabora	155	**2.8**
Total	2,912	**3.4**

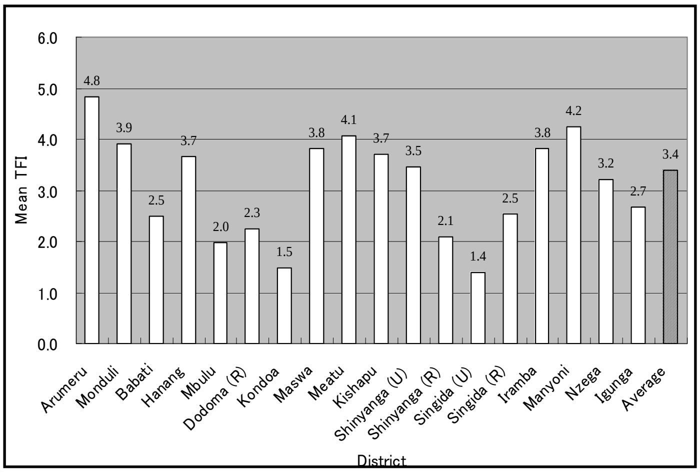


Figure 3-25 Mean TFI by District

(4) Relationship between Fluoride of Water and Fluorosis

This survey set out to know the actual conditions of dental fluorosis in IDB, not to prove the correlation between fluoride of water and dental fluorosis without a full-scale epidemiological study; however, it is worth including an overview here of the relationship between them.

Figure 3-26 shows the relationship between TFI of each village and fluoride levels in water. The fluoride level is based on the results of the water quality survey conducted by the Study Team in the dry season of 2006. Although there are several extraordinary data items in the figure, it implies a relationship somewhat between them. However, conducting accurate statistical analysis using "Pearson Correlation" indicated a non-significant association between them.
The reason why there was not a clear correlation shown is due to the complexity of individual fluoride impact from drinking water and Magadi. The villagers are strongly affected by their living activities throughout the year. Furthermore, water sources where the water quality survey was conducted and the water sources used by the examinees did not always match.

Table 3-14 shows the fluoride content in Magadi samples taken from the target villages. The variable content by region and Magadi sample is too great, so fluoride impact caused by ingestion of Magadi is extremely complicated. Distribution of mean TFI by survey village is illustrated as shown in Figure 3-28.

Table 3- 14 Fluoride Content of Magadi

Region	No. of Sample	Mean F (mg/kg)	Range of F (mg/kg)	
			Min.	Max.
Arusha	4	12,660	1,138	23,000
Dodoma	3	2,025	44	5,978
Manyara	7	222	4	1,199
Shinyanga	39	2,648	4	12,074
Singida	32	3,636	3	31,000
Tabora	5	3,455	46	11,000
Total	**90**	**3,455**	**3**	**31,000**

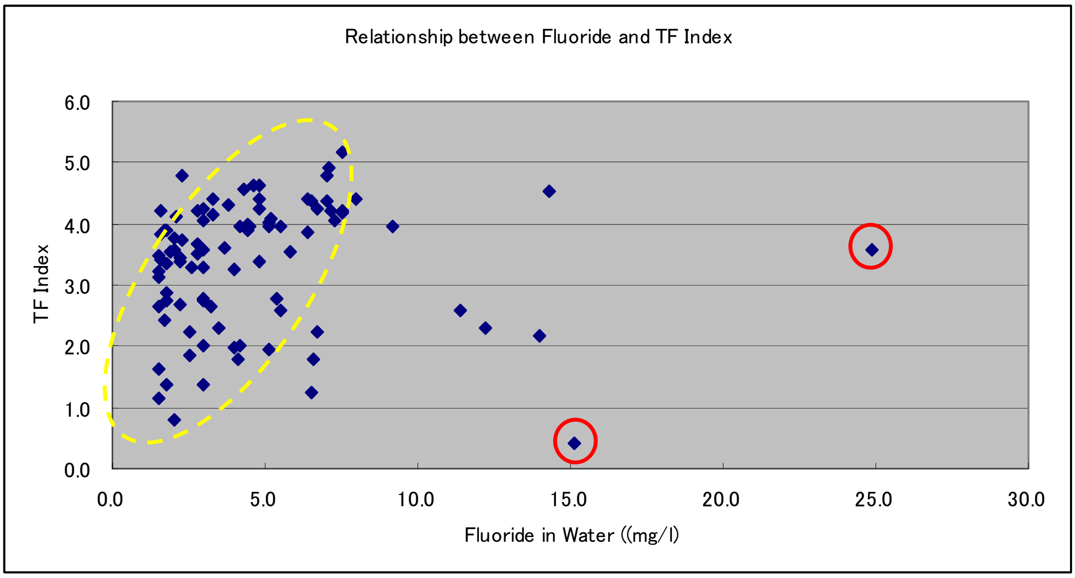


Figure 3-26 Relationship between Fluoride of Water and TFI

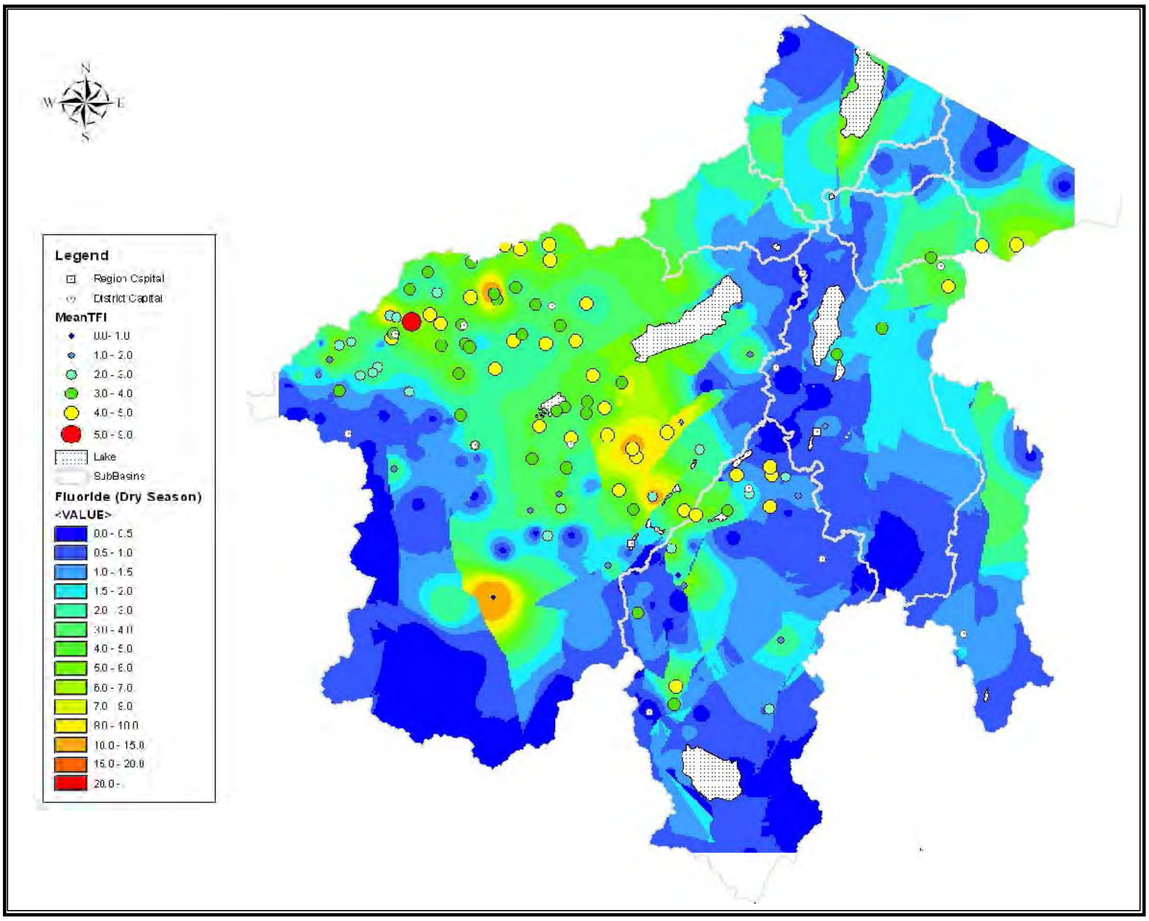


Figure 3-27 Distribution of Mean TFI by Survey Village and Fluoride Concentration of Water in Dry Season of 2006

(5) Results of Questionnaire

Table 3-15 gives the outline of the questionnaire survey, which was conducted as a part of dental fluorosis survey. More than 94.6 percent of examinees acknowledged that people in their respective villages had fluorotic teeth. Sixty-eight percent reported awareness of their own teeth showing fluorotic symptoms and about the same proportion reported that their family members also had fluorotic teeth. Fifty-nine percent reported that having fluorotic teeth was a cause for embarrassment. About two-thirds (66.2 %) felt a sense of frustration from having fluorotic teeth, and 48.4% claimed to feel inferior because of fluorotic teeth. About two thirds (59.6 %) indicated that they were not satisfied with their physical appearance and that they considered

Table 3-15 Outline of Questionnaire Survey on Dental Fluorosis

Question on Dental Fluorosis	Yes		No		Total
	no.	%	no.	%	no.
Seen fluorotic teeth in village	2,747	94.6	155	5.3	2,902
Own teeth are fluorotic	1,993	68.7	909	31.3	2,902
Family member have fluorotic teeth	1,955	67.4	945	32.6	2,900
Fluoride in water cause fluorosis	1,082	37.2	1,829	62.8	2,911
Fluoride in magadi cause fluorosis	703	24.1	2,208	75.9	2,911
Fluorosis is inherited	164	5.6	2,746	94.4	2,910
Fluorosis is caused by tooth decay	213	7.3	2,698	92.7	2,911
Stop using high fluoride magadi prevents fluorosis	742	25.5	2,169	74.5	2,911
Stop using high fluoride water prevents fluorosis	956	32.8	1,955	67.2	2,911

themselves less attractive (62.0%). The mean score for perception indicates that these examinees were inclined towards high scores of the scale, which expresses their dissatisfaction with brown teeth.

Only 37.2% of the examinees knew that water with high levels of fluoride would lead to dental fluorosis and even a much lower proportion (24.1 %) knew that high fluoride Magadi would cause dental fluorosis. A small proportion worth noting is the 5.6% who believed that dental fluorosis is inherited from parents and some (7.3 %) that thought dental fluorosis is caused by tooth decay. There was common understanding that poor oral hygiene causes brownish discolouration of teeth, i.e. dental fluorosis. Overall, the data points to the fact that a large proportion did not know what causes dental fluorosis.

Questionnaire findings indicated that water was obtained from the following regular sources: shallow wells (48%), tap water mainly from deep wells 21.5 %, permanent and temporary rivers (20.9 %), spring (3.9 %), dam/lake (3.9 %), unknown sources 1.6 % and rainwater 0.1 %. (Refer to Figure 3-28) However, only 60.6 % of examinees obtained water from the same water source for the year and they regularly used more than one source in the same village.

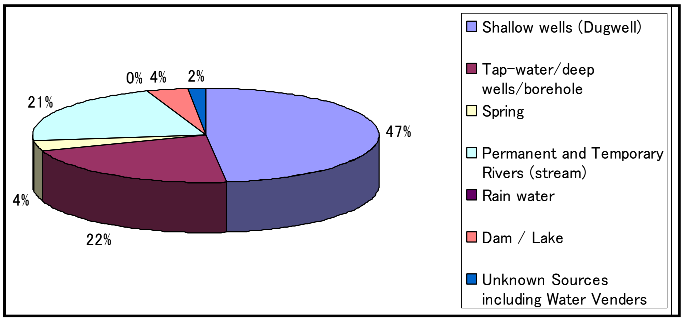


Figure 3-28 Regular Water Source of Examinee

3.5.7 Countermeasure against Fluorosis

Fluorosis in IDB was confirmed by the dental fluorosis survey of the Study. There are several ways to remove fluoride technically from water, but from a socio-economical point of view, applicability was concluded to be very difficult in IDB, particularly in the rural areas. Nonetheless, it is possible to conduct awareness campaigns of fluoride problems, guidance of better water sources and restriction of Magadi use as temporary measures in terms of impact or risk management prior to a full-scale countermeasure against fluorosis.