Chapter 6
Test Borehole Drilling Survey

CHAPTER 6 TEST BOREHOLE DRILLING SURVEY

6.1 Purpose of Survey

Test borehole drilling survey consists of drilling work, logging test, well construction and pumping test. This survey was carried out to obtain the following information:

- Geological condition,
- Geological structure,
- Groundwater condition,
- Aquifer contents,
- Complement for the existing borehole data, and
- Monitoring groundwater level and water quality.

This information from the survey is fundamental data for water quality analysis, water balance analysis and establishment of hydrogeological map.

6.2 Drilling Work

6.2.1 Outline of the Work

The drilling work was conducted at thirty (30) sites in this study. The location of them is shown in Figure. 6-1 and Table. 6-1.

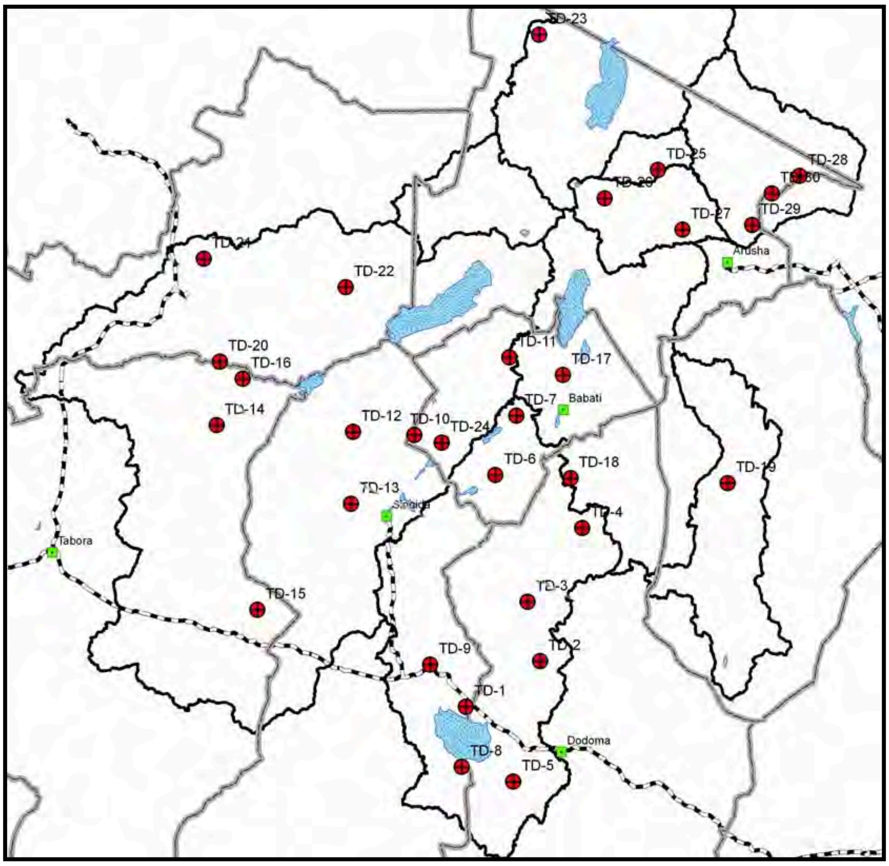


Figure 6-1 Location Map of the Test Borehole Drilling Survey

Table 6-1 Location of Test Borehole Drilling Survey

DR-No.	Region	District	Division	Ward	Village	Longitude	Laitude	Catch ment	Target Geology	Target Aquifer	Drilled Depth (m)	Static Water Level (GL- m)
TD-1	Singida	Manyoni		Kintinku	Lusilile	35.19819	-5.91837	G	Nf	Sediment	100.0	12.05
TD-2	Dodoma	Dodoma Rural	Munoemu	Babayu	Kongogo	35.62646	-5.65423	G	gs	Weathered/Fractured	130.0	28.30
TD-3	Dodoma	Kondoa	Farkwa	Farkwa	Bubutole	35.55380	-5.31306	G	gs	Weathered	80.0	28.40
TD-4	Dodoma	Kondoa	Pahi	Kalamba	Loo	35.87000	-4.88863	G	Xs	Fractured	100.0	8.70
TD-5	Dodoma	Dodoma Rural	Chipalamga	Mpalanga	Nholi	35.47181	-6.34712	G	D	Fractured	105.0	17.35
TD-6	Manyana	Hanang	Katesh	Balangi Dalalu	Numbeta	35.36895	-4.58404	G	Nvd	Weatherd volcanic rock	120.0	-
TD-7	Manyara	Babati	Bashanet	Dareda	Bermi/Seloto	35.48875	-4.24282	G	gs	Fault	80.0	31.20
TD-8	Singida	Manyoni	Nkonko	Sanza	Ikasi	35.17442	-6.26388	G	Nf	Fault	120.0	34.70
TD-9	Singida	Manyoni	Kilimatinde	Makuru	Ilalo	34.99325	-5.67618	G	gs	Fractured	135.0	-
TD-10	Manyara	Hanang	Bassuto	Hirbadaw	Hirbadaw	34.90203	-4.35454	A	N	Fractured	147.5	31.75
TD-11	Manyara	Mbulu	Endagikot	Tlawi	Tlawi	35.44907	-3.90797	A	Xs	Fractured	101.0	10.68
TD-12	Singida	Iramba	Kinyangili	Msingi	Misingi	34.54847	-4.33553	A	gs	Fractured or Weathered or Sediment	100.0	7.00
TD-13	Singida	Singida Rural	Sepuka	Sepuka	Sepuka	34.53607	-4.74932	A	gs	Weathered	45.0	3.20
TD-14	Tabora	Igunga	Nanga	Nanga	Igogo	33.76144	-4.29724	A	Z	Weathered	100.0	-
TD-15	Tabora	Uyui	Igalula	Kizengi	Nkongwa	33.99646	-5.36013	A	gs	Weathered or Sediment	60.0	7.70
TD-16	Tabora	Igunga	Igurubi	Mwamashima	Kininginila	33.91155	-4.03112	A	Nl	Sediment	80.0	40.50
TD-17	Manyara	Babati	Mbugwe	Magugu	Mapea	35.75789	-4.00821	D	N	Sediment	80.0	8.38
TD-18	Dodoma	Kondoa	Bereko	Masange	Masange	35.80318	-4.60344	D	Xs-l	Fractured	70.0	68.90
TD-19	Manyara	Kiteto	Makami	Makame	Makeme	36.70853	-4.63158	H	N	Fractured	75.0	35.70
TD-20	Shinyanga	Kishapu	Negezi	Ngofila	Ngofila	33.78151	-3.93233	A	Nl	Sediment	75.0	4.30
TD-21	Shinyanga	Maswa	Nughu/Kigoku	Masela	Mwasayi	33.68677	-3.34095	A	gs-a	Weathered/Fractured	70.0	4.40
TD-22	Shinyanga	Meatu	Kimari	Kimari	Mwangudo	34.50635	-3.50460	A	gs	Weathered/Fractured	100.0	-
TD-23	Arusha	Ngorongoro	Loliondo	Orgosorok	Loliondo	35.61991	-2.05134	E	Xs	Weathered/Fractured	100.0	13.09
TD-24	Manyara	Hanang	Basotu	Bassotu	Bassotu	35.06010	-4.39915	A	Z	Fractured	100.0	15.09
TD-25	Arusha	Longido	Kitumbein	Kitumbein	Orkejuloongishu	36.30634	-2.82878	C	Nvd	Fault	50.0	-
TD-26	Arusha	Monduli	Manyara	Engaruka	Engaruka Chini	35.99940	-2.99348	B	Nvd	Sediment	130.0	-
TD-27	Arusha	Monduli	Kisongo	Monduli Juu	Mfereji	36.44655	-3.17237	B	Nv	Weathered/Fractured	100.0	-
TD-28	Arusha	Longido	Enduimet	Olmolog	Olmolog	37.12249	-2.86338	I	Nv	Weathered/Fractured	100.0	-
TD-29	Arusha	Arumeru	Kingori	Ngarenanyuki	Uwiro	36.84932	-3.14609	I	Nv	Fractured	105.0	25.00
TD-30	Arusha	Longido	Sinya	Tingatinga	Tingatinga	36.96155	-2.96533	I	Nvd	Sediment	130.0	-

The casing program was determined based on the results of drilling and borehole logging. Pumping test was carried out after the well construction.

6.2.2 Specification of Survey

This survey was carried out under the following specification:

(1) Drilling

Rotary boring machine was applied for the soft soil layer, and "Down the Hole Hammer" drilling machine was applied for the weathered or hard rocks.

Casing pipe and suitable drilling fluid were used properly to maintain the borehole wall.

The diameter of borehole was performed 250mm for the rotary drilling, and 200mm for the Down the Hole Hammer drilling.

Groundwater level and groundwater electric conductivity were measured when the first water strike is found. The measurements were conducted at the beginning and the end of every working day.

Typical drilling cutting samples were preserved in a plastic bag with sampling depth note. The samples were kept to prevent the change of sample condition during the survey.

After completion of the drilling, the geophysical borehole logging was carried out.

(2) Well Construction

1) Standard Well Structure

The standard well structure is shown in Figure.6-2

- Casing Pipe: diameter 6 inches (150mm), PVC
- Screen Pipe: diameter 6 inches (150mm), PVC with slits

2) Casing Pipe Diameter

The diameter of the casing pipe was determined as 150 mm which is enough to install a standard submersible pump to conduct the pumping test.

3) Screen Pipe

PVC pipe with slit was used as the screen pipe. Setting depth and length of the screen pipe was determined based on the results of the drilling and the geophysical borehole logging.

The slot width of the slit is 1 mm. For the casing and screen pipe, 7.5 mm thick PVC pipe was used .

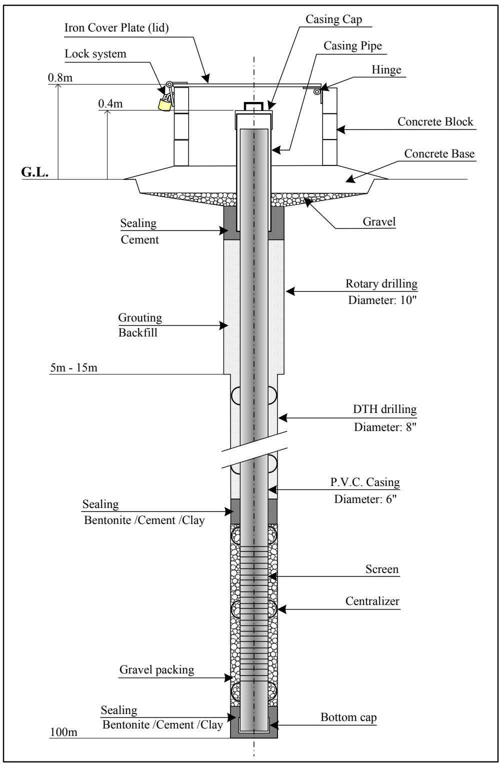


Figure 6-2 Schematic Diagram of Well Structure

4) Filter Packing and Sealing

Gravel which was siliceous material, clean and well-rounded was used for filter packing. Its grain size is 3 to 8 mm. The range of filter packing section was at least two (2) m more than the screen. The sealing at least one (1) m range was put on the top and bottom of the filter packing section. The residential soil was used for the backfilling.

5) Protection

Cementation was conducted around the mouth of the borehole to fix and protect the casing. Finally, the protection box with lock was set up. (Refer to Photo 6-2)

(3) Well Development

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

6.2.3 Drilling Procedure

A flow chart of the drilling work is shown in Figure 6-3. The Drilling work was carried out as follows:

(1) Selection of Survey Area

Candidate areas for test borehole drilling point were selected based on geological condition, population, density of existing data and so on.
(Refer to Chapter 5)

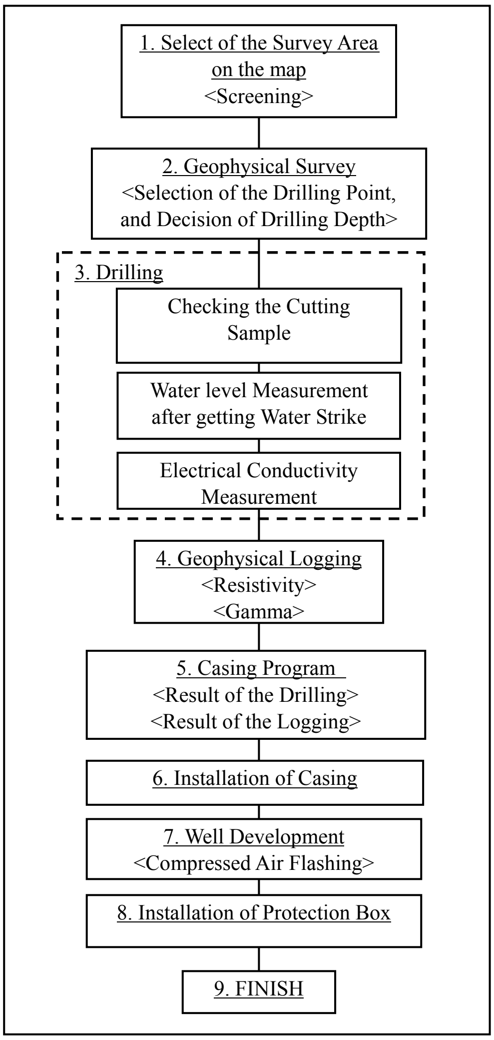


Figure 6-3 Flow Chart of Drilling Work

(2) Geophysical Survey

Geophysical survey was conducted at least 3 points in the selected areas. The drilling points were finally determined based on the results of this survey.
(Refer to Chapter 5)

(3) Drilling

Drilling works consisted of collecting cutting samples every 2.5m depth, water level measurement and electrical conductivity measurement. When a water strike was found, the drilling was interrupted until the water level showed stable. Then water level and electrical conductivity were measured. After drilling depth reached to the specified depth, borehole was cleaned up by air lifting.

(4) Geophysical Borehole Logging

The geophysical borehole logging was conducted in the borehole when water level was found as enough depth to conduct the logging. Electrical resistivity and Natural Gamma were measured by the logging machine.

(5) Casing Program

The casing program is for the screen and the grouting plan. The casing program of each borehole was decided based on the results of drilling and logging. The screen was installed into all boreholes even if sufficient groundwater was not found.

Photo 6-1 Casing Installation

(6) Installation of Casing

Based on the casing program, casing pipes and screen pipes were installed. After the installation of the casing and screen pipe, the back filling, sealing and filter packing were conducted.

Photo 6-2 Protection Box

(7) Well Development

After the above mentioned process, the borehole was cleaned up by air lifting. The purpose of this process is to remove soil materials that stick to aquifer or screen and deposited on the bottom of the casing pipe.

(8) Installation of Protection Box

Cementation was conducted around the mouth of the borehole to fix and protect the casing pipe. Finally, the protection box with lock was set up.

6.2.4 Drilling Method

Basically, the rotary drilling with drag bit (refer to Photo 6-3) was applied for the sedimentary layer and unconsolidated soil. The down the hole hummer drilling with hummer bit (refer to Photo 6-4) was applied for the hard rocks: namely, the basement rocks. Hammering was functioned by compressed air. The hummer made a hole removing cutting debris by air simultaneously. In the case of soft layer: especially upper loose layer, the surface casing was installed to avoid collapse of borehole wall during the drilling work. When the soft layer was so thick, mud drilling was applied to avoid collapse of the borehole wall.

Photo 6-3 Drag Bit

Photo 6-4 Hummer Bit

6.2.5 Sampling, Measurement and Testing

Cutting sample was taken from the cutting debris which was retrieved by compressed air. It was taken every 2.5m depth drilling and stored in sample box (refer to Photo6-5). Geological information which was taken from the sample was used for the casing program. When water strike was found in the drilling progress, the drilling work was interrupted until groundwater level was stabilized. Then water level was measured and the water was taken by sampler to measure electrical conductivity.

Photo 6-5 Sample Box

6.2.6 Borehole Logging

Borehole logging consists of the electrical resistivity logging and the natural gamma logging. GW Combination Measuring System was applied fro this survey. The specification of this system, which is manufactured by OYO Corporation, is composed of the following items:

-Measuring Unit: Geologger-3030
-Measuring Module: GW Combination Measuring Module (MODEL-3433)
-Measuring Probe: GW Combination Probe (MODEL-3493)

Electrical resistivity and natural gamma are useful items to categorize geology into permeable layer and impermeable layer. The data obtained by the loggings were used for the casing program.

(1) Electrical Resistivity

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

(2) Natural Gamma

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

(3) Result of the Logging

Figure. 6-4, 5 show the examples of the logging survey results. The ranges shown by red bars in the electrical resistiveity Figurer are expected high water contents layer and the positions shown by red arrows in the Natural Gamma curves are expected low contents of clay. The results of the analysis were applied to the casing program for the test boreholes.

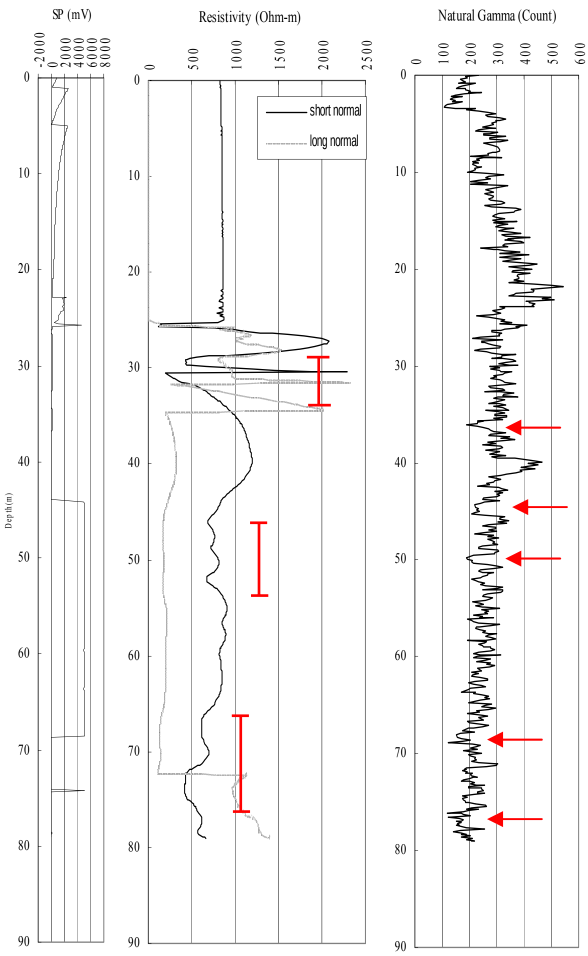


Figure 6-4 Result of the Loggings in No. 3 Bubutole

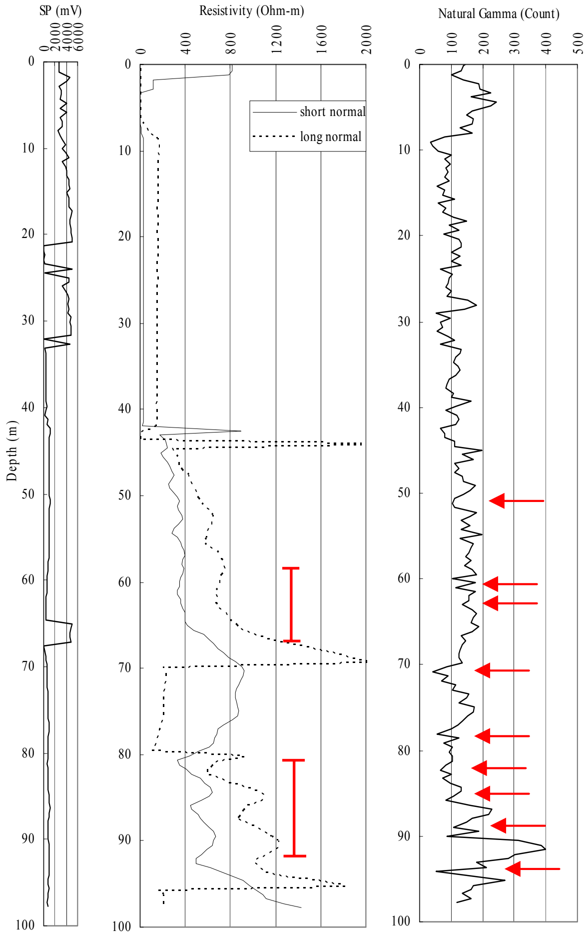


Figure 6-5 Result of the Loggings in No. 4 Loo

6.2.7 Result of Drilling

Borehole Logs are attached in the Data Book. The summary of each borehole is descried below.

Borehole No. **TD-1**
Location: Lusilile (Singida region)
Depth of Borehole: 100m Water Level: GL-12.05m

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Laterite
5.00 - 20.00	Sand with gravel	Coarse sand with gravel. Gravel is expressed angular shape. Biotite and muscovite are found in the cutting sample.
20.00 - 45.00	Granite	Highly weathered granite. Quartz, Biotite, muscovite are found in the cutting sample. Fractured zone.
45.00 - 100.00	Rhyolite	Highly to moderate weathered rhyolite.

The water level was not found in the borehole; however, the screen has been installed the following depth on the assumption that groundwater will appear in the sand with gravel layer in the rainy season. The depth of the screen section is decided on the basis of the drilling result.

- Screen section: GL-16.40-22.30m and GL-28.20-37.05m

Borehole No. **TD-2**
Location: Kongogo (Dodoma region)
Depth of Borehole: 105m Water Level: GL-8.16m

Depth (GL -m)	Lithology	Description
0.00 - 7.50	Clay with sand	Clay with medium sand.
7.50 - 27.50	Clayey sand	Fine to medium sand with clay. Slightly moisture at GL-30m.
27.50 - 57.50	Sand with gravel	Fine to medium sand with gravel. The gravels are expressed 5mm, and rounded shape. Moderate moisture at GL-50m.
57.50 - 105.00	Granite	Highly to moderate weathered granite. Water strike at GL-57.5m

The water strike was found at GL-57.5m at the boundary of sedimentary layer and bedrock. The screen was installed at following sections based on the result of drilling and geophysical logging.

- Screen section: GL-49.65-73.25m and GL-79.15-93.90m

Borehole No. **TD-3**
Location: Bubutole (Dodoma region)
Depth of Borehole: 80m Water Level: GL-28.44m

Depth (GL -m)	Lithology	Description
0.00 - 2.00	Overburden	Sandy clay
2.00 - 22.50	Sandy clay	Clay with medium sand.
22.50 - 33.00	Sand with gravel	Medium to coarse sand with 0.5mm gravel.
33.00 - 80.00	Granitic gneiss	Highly to moderate weathered gneiss. Quartz, Biotite and garnet in the cutting sample. Water strike at GL-33m.

The water strike was found at GL-33m where was near the boundary of sedimentary layer and bedrocks. This groundwater was contained in the sediment layers. On the other hand, the some sections where were at GL-33m, GL-47-55m and GL-72.5-75m were shown as aquifer based on the geophysical loggings survey. The aquifers at GL-47-55m and GL-72.5-75m were fractured or weathered zone in the bedrock. Since the target aquifer of this drilling area was weathered zone, the screen pipes were installed at the following sections:

- Screen section: GL-46.65-55.5m and GL-72.1-76.2m

Borehole No. **TD-4**
Location: Loo (Dodoma region)
Depth of Borehole: 100m Water Level: GL-8.7m

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Laterite
5.00 - 22.50	Sandy clay	Clay with coarse sand. Around GL-15m, gravels are found. Water strike at GL-17.5m
22.50 - 90.00	Granitic gneiss	Highly to moderate weathered gneiss. Rock fragments in the cutting sample are 2-5mm. GL-60-85m: Fractured zone. GL-85-90m: weathered zone
90.00 - 100.00	Granitic gneiss	Slightly weathered gneiss. Quartz, Biotite and garnet are found in the cutting sample.

The first water strike was found at GL-17.5m which was estimated as shallow groundwater related to the surface water flow. After GL-70m, plenty of groundwater was confirmed as another water strike. The ranges of GL-60-67m and GL-80-92m were presumed as the aquifer based on the logging test. Since the target aquifer of this drilling area was fractured zone, the screen pipes were installed at the following section in the fractured/weathered zone in the bedrock.

- Screen section: GL-64.6 - 88.2 m

Borehole No. **TD-5**
Location: Nholi (Singida region)
Depth of Borehole: 100m Water Level: GL-17.35m

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Silicic sand. Fine grained.
5.00 - 20.00	Sand with gravel	Fine to coarse sand with gravel. Gravel is around 6mm, and angular shape.
20.00 - 65.00	Granite	Highly weathered granite. Quartz and Biotite are found in the cutting sample. Water strikes are found at GL-52.5m and GL-61m.
65.00 - 100.00	Granite	Slightly weathered granite. Water strike is found at GL-72m.

All water strikes were found in the weathered zones: GL-52.5m and GL-61m and fractured zone: GL-72m. Based on the geophysical logging, aquifer was presumed at GL-58-63m, GL-72.5-77.6m and GL-89-93m. Then, the screen pipes were installed the following sections:
- Screen section: GL-49.9-61.7m, GL-67.6-76.5m and GL-88.3-97.1m

Borehole No. **TD-6**
Location: Nnmbeta (Manyara region)
Depth of Borehole: 120m Water Level: No Water level

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Laterite.
5.00 - 45.00	Tuff	Basaltic tuff. Highly weathered. Muscovite is found in the cutting sample.
45.00 - 47.50	Schist	Moderate weathered schist. Muscovite are found in the sample.
47.50 - 67.50	Pyroclastic rock	Highly to moderate weathered rock. Biotite and muscovite are found in the sample.
67.50 - 120.00	Pyroclastic rock	Slightly weathered rock. Biotite and feldspar are found. Fractured zone.

Although the water level was not found in the borehole, the screen pipes were installed at the following depth on the assumption that groundwater would appear in the weathered and fractured zones in the rainy season. The depth of screen pipes was determined on the basis of the drilling result.
- Screen section: GL-52.5-70.2m

Borehole No. **TD-7**
Location: Barmi/Seloto (Manyara region)
Depth of Borehole: 80m Water Level: GL-30.8m

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Laterite
5.00 - 10.00	Clay	Light gray clay. Coarse sand are found partially.
10.00 - 20.00	Sand with gravel	Sand with angular gravel. Gravel size is less than 3mm.
20.00 - 37.50	Gneiss	Highly weathered gneiss. Almost cutting sample is expressed as sandy to silty.
37.50 - 80.00	Gneiss	Slightly to moderate weathered gneiss. The cutting sample is expressed as angular gravel Water strike is found at GL-53m. Fractured zone.

The water strike was found in the fracture zone around GL-53 m. Based on of the geophysical logging, aquifer was presumed at GL-42-45 m, GL-58 m and GL-70-74 m. Then, the screen pipes were installed at the following sections:

- Screen section: GL-39.15-45.05 m and GL-50.95-74.55 m

Borehole No. **TD-8**
Location: Ikasi (Singida region)
Depth of Borehole: 120m Water Level: GL-34.7m

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Laterite.
5.00 - 10.00	Clayey sand	Brownish coarse sand with clay.
10.00 - 80.00	Granite	Highly weathered granite. Almost cutting sample is expressed as sandy. Water strikes are found at GL-47m and GL-70m.
80.00 - 120.00	Granite	Moderate weathered granite. This section is estimated as fractured zone, especially GL-90-120m.

The water strikes were found in the fractured zone at GL-47 m and Gl-70 m. Based on of the geophysical logging, aquifer was presumed at GL-42-48 m, GL-70-76 m and GL-95-100 m. Then, the screen pipes were installed at the following sections:

- Screen section: GL-40.8-49.65 m, Gl-67.35-85.05 m and Gl-90.95-117.5 m.

Borehole No. **TD-9**
Location: Ilalo (Singida region)
Depth of Borehole: 135m Water Level: No Water level

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Laterite
5.00 - 25.00	Sand with gravel	Medium to coarse sand with rounded gravel.
25.00 - 65.00	Granite	Highly weathered granite. Rounded quartz sample is found in the cutting sample.
65.00 - 135.00	Granite	Moderate weathered granite.

Although the water level was not found in the borehole, the screen pipes were installed at the following depth on the assumption that groundwater would appear in the sedimentary layers in the rainy season. The depth of screen section was determined on the basis of the drilling result.

- Screen section: GL-14.7-23.55 m

Borehole No. **TD-10**
Location: Hirbadaw (Manyara region)
Depth of Borehole: 147.5m Water Level: GL-30.3m

Depth (GL -m)	Lithology	Description
0.00 - 0.30	Overburden	Laterite.
0.30 - 40.00	Granite	Highly weathered granite. Moderate weathered granite samples are found partially.
40.00 - 82.50	Granite	Moderate weathered granite. Angular rock fragment is found. Fractured zone.
82.50 - 117.50	Granite	Slightly weathered granite. The cutting sample is expressed as sandy. Water strike is found at around GL-110m.
117.50 - 127.50	Granite	Highly weathered rock. The cutting sample is expressed as sandy to silty. No rock fragment.
127.50 - 147.50	Granite	Slightly weathered rock. Quartz and biotite and feldspar are found.

The water strike was found at around GL-110 m in the fractured zone. Based on of the geophysical logging, aquifer was presumed at GL-87.5 m, GL-93 m, GL-102 m, and GL-112-130 m. Then, the screen pipes were installed at the following sections in the fractured and weathered zone.

- Screen section: GL-115.1-138.65 m

Borehole No. **TD-11**
Location: Tlawi (Manyara region)
Depth of Borehole: 101m Water Level: GL-10.68m

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Laterite
5.00 - 12.50	Clay with sand	Stiff clay with medium to coarse sand. The sand is rounded shape.
20.00 - 60.00	Gneiss	Highly to moderate weathered gneiss. From GL-45m, slightly weathered rock. The cutting sample is expressed as sandy to silty. Few rock fragments are found.
60.00 - 85.00	Schist	Slightly weathered schist. Gray color. Water strike is found at GL-65m.
85.00 -101.00	Gneiss	Slightly weathered gneiss. Amount of the returned water is increase at GL-87m.

The all water strikes were found in fractured zone at GL-65 m and GL-87 m. Based on of the geophysical logging, aquifer was presumed at GL-25-42 m in the weathered zone and GL-63-78 m, GL-86m in the fractured zone. Then, the screen pipes were installed at the following section in the fractured zone.

- Screen section: GL-62.65-86.25 m

Borehole No. **TD-12**
Location: Misingi (Singida region)
Depth of Borehole: 100m Water Level: GL-7.0m

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Laterite.
5.00 - 45.00	Sand with gravel	Medium to coarse sand with gravel. The gravel is granite. Quartz, muscovite and feldspar are found in the sample.
45.00 - 60.00	Granite	Highly weathered granite. Water strike is found at GL-49m.
60.00 - 90.00	Granite	Moderate weathered granite. Water strikes are found at GL-62m and GL-72m. Fractured zone.
90.00 -100.00	Granite	Slightly weathered granite. Biotite and feldspar are found. Fractured zone.

The water strikes were found in the weathered zone at GL-49 m and the fractured zone at GL-62 m and GL-72 m. Based on the geophysical logging, aquifer was presumed at the following sections: GL-18-27 m, GL-40 m, GL-45-51 m and Gl-61-85 m. The screen pipes were installed at the following sections in the weathered and fractured zones.

- Screen section: GL-44.85-53.7 m, GL-59.6-65.5 m, GL-71.4-80.25 m and GL-86.15-92.0 m.

Borehole No. **TD-13**
Location: Sepuka (Singida region)
Depth of Borehole: 45m Water Level: GL-3.2m

Depth (GL -m)	Lithology	Description
0.00 - 7.50	Sand	Coarse sand. Brown color.
7.50 - 42.50	Granite	Highly to moderate weathered granite. Water strike: GL-30m and GL-40m
42.50 - 45.00	Granite	Slightly weathered granite.

The water strikes were found in the weathered zone at GL-30 m and the fractured zone at GL-40 m. Based on the geophysical logging survey, aquifer was presumed at GL-25-27m. Then, the screen pipes were installed at the following sections in the fractured zone only.

- Screen section: GL-36.15-42.05m

Borehole No. **TD-14**
Location: Igogo (Tabora region)
Depth of Borehole: 100m Water Level: No Water level

Depth (GL -m)	Lithology	Description
0.00 - 10.00	Overburden	Laterite.
10.00 - 60.00	Clay	Light gray to brown clay. The cutting sample is expressed as flaky. No moisture.
60.00 - 90.00	Sandy clay with gravel	Brown clay with grave. Gravels are originated from banded iron rock, and angular shape.
90.00 - 100.00	Banded Iron Rock	Slightly weathered rock.

Although the water level was not found in the borehole, the screen pipes were installed at the following depths on the assumption that groundwater would appear in the sedimentary layer or fractured zone in the bedrock in the rainy season. The position of screen pipes was determined based on the drilling result.

- Screen section: GL-67.4-82.1 m and GL-88.0-96.85 m

Borehole No.: **TD-15**
Location: Nkongwa (Tabora region)
Depth of Borehole: 60m   Water Level: GL-7.7m

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Medium to coarse sand originated from granite.
5.00 - 37.50	Granite	Highly weathered granite. Medium to coarse sandy sample. Water strike: GL-22m and GL-37m.
37.50 - 60.00	Granite	Moderate weathered granite. Fine to coarse sandy sample. Partially, the sample is silicic.

The water strikes were found in the weathered zone at GL-22 m and GL-37 m. Based on the geophysical logging, aquifer was presumed at GL-35-37 m and GL-47-52 m. Then, the screen pipes were installed at the following sections in the fractured and the weathered zone.

- Screen section: GL-29.0-37.85m and GL-46.7-58.5m

Borehole No.: **TD-16**
Location: Kininginila (Tabora region)
Depth of Borehole: 80.0m   Water Level: GL-60.0m

Depth (GL -m)	Lithology	Description
0.00 - 0.80	Overburden	Topsoil. Clay.
0.80 - 25.00	Clay	Calcareous clay to silt. No moisture. Partially, rounded sand is found.
25.00 - 47.50	Clay	Calcareous clay with gravel. The gravel is laterite. Partially, sample has moisture.
47.50 - 77.50	Clay	Moisture silty clay. The clay is expressed two colors, reddish brown and brownish gray alternately.
77.50 - 80.00	Silt rock	Consolidated silt.

The water strike was not found clearly. After passing through around GL-50 m, water level was found. The water level was confirmed at GL-41 m. At GL-80 m, water level was GL-60 m. Based on the geophysical logging, aquifer was presumed at GL-62m and GL-68 m, the screens were installed at the following sections in sedimentary layers where were found gravel and moisture zone.

- Screen section: GL-24.9-30.8m, GL-36.7-42.6m, GL-48.5-54.4m GL-60.6-66.2m and GL-72.1-75.05m

Borehole No. **TD-17**
Location: Mapea (Manyara region)
Depth of Borehole: 80m Water Level: GL-5.0m

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Dark gray clay.
5.00 - 15.00	Clay	Gray clay. The cutting sample is expressed as flaky.
15.00 - 35.00	Sand	Clayey sand. Fine to medium sand. Gravel is found. Water strike: GL-27m
35.00 - 45.00	Clay with silt	Clay with silt. The second water strike: GL-40m
45.00 - 80.00	Gneiss	Highly weathered gneiss. The third water strike: GL-72m

The water strikes were found in the sedimentary layers: GL-27 m, GL-40 m and weathered zone at GL-72 m. Since the sedimentary layer was very loose, the mud drilling was applied. Therefore, the geophysical logging could not be conducted because of threatening probe jammed. The casing program was made based on the drilling result. The screen pipes were installed the following sections.
- Screen section: GL-20.5-29.4m, GL-35.28-44.1m, GL-49.98-58.8m and GL-64.68-73.5m

Borehole No. **TD-18**
Location: Masange (Dodoma region)
Depth of Borehole: 70.0m Water Level: GL-68.9m

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Laterite.
5.00 - 12.50	Gneiss	Highly weathered gneiss. Quartz and mica are found in the sample.
12.50 - 27.50	Gneiss	Moderate weathered gneiss. Quartz, mica and feldspar are found. The sample has slightly moisture.
27.50 - 35.00	Gneiss	Slightly to moderate weathered gneiss. Fractured zone.
35.00 - 70.00	Gneiss	Slightly weathered gneiss. No moisture.

The water strike was not found clearly. After passing through around GL-50m, water level was found. The water level was GL-37.45m. Since water level was GL-68.9m at drilled depth: GL-70m, the geophysical logging could not be conducted. The casing program was made based on the drilling result. The screen pipes were installed at the following sections in the fractured zone.
- Screen section: GL-22.8-37.55m.

Borehole No. **TD-19**
Location: Makame (Manyara region)
Depth of Borehole: 75m Water Level: GL-35.7m

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Laterite
5.00 - 17.50	Sand	Coarse sand. Brown.
17.50 - 45.00	Gneiss	Highly to moderate weathered gneiss. Quartz and Biotite are found.
45.00 - 75.00	Gneiss	Slightly to moderate weathered gneiss. Water strike: GL-46m and GL-68m

The water strikes were found in the weathered zone: GL-46m and GL-68m. The screen pipes were installed at the following sections in the weathered zone base on the drilling result.

- Screen section: GL-48.45-57.3m and GL-60.25-66.15m

Borehole No. **TD-20**
Location: Ngofila (Shinyanga region)
Depth of Borehole: 75.0m Water Level: GL-4.3m

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Topsoil. Clay.
5.00 - 17.50	Clay with gravel	Calcareous clay and gravel. Angular gravels are found.
17.50 - 25.00	Sand	Medium sandy quartz is found in the sample.
25.00 - 45.00	Clayey sand	The cutting sample is expressed as flaky. The size is 5-8mm.
45.00 - 75.00	Sand	Medium to coarse sand. Angular shape. Clay with sand layer. GL-45m from GL-60-65m, clayey sand layer.

The water strike was found around GL-50m in the sedimentary layer. Since the sedimentary layer was very loose, the mud drilling was applied. Then, the geophysical logging could not be conducted because of threatening probe jammed. The casing program was made based on the drilling result. The screen pipes were installed at the following sections:

- Screen section: GL-48.45-57.3m and GL-60.25-72.05m

Borehole No. **TD-21**
Location: Mwasayi (Shinyanga region)
Depth of Borehole: 70.0m Water Level: GL-5.9m

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Fine Sand	Sand with gravels, including angular shape gravels
5.00 - 20.00	Pegmatite	Weathered pegmatite. Light reddish gray. Cutting sample; Fine-midium sandy fragments. Small ratio of quartz contents
20.00 - 35.00	Pegmatite	Moderate weathered. Dark gray. Cutting sample: Sandy and clayey condition
35.00 - 70.00	Pegmatite	Moderate weathered. Dark gray. Cutting sample: 1 - 2mm rock fragment.

The water strikes were found in the fractured zone: GL-5m, GL-21m and GL-35m. The screen pipes were installed at the following sections in the fractured zone.

- Screen section: GL-20.20 - 22.94m, GL-25.90 - 28.84m, GL-31.78 - 34.72m, GL-40.60 - 49.42m, GL-52.36 - 61.18m and GL-64.12 - 67.06m

Borehole No. **TD-22**
Location: Mwangudo (Shinyanga region)
Depth of Borehole: 100.0m Water Level : No water level

Depth (GL -m)	Lithology	Description
0.00 - 2.50	Overburden	Sandy clay.
2.50 - 12.50	Granite	Highly weathered granite. Quartz vein are found on the cutting samples
12.50 - 22.50	Diorite	Weathered Diorite. Blackish gray. 5 -20mm rock fragment. Including potassium feldspar
22.50 - 45.00	Granite	Quartz vein are found on the cutting samples. Biotite / muscovite:
45.00 - 100.00	Granite	Cutting sample : Biotite, Feldspar, Quartz, Gray rock fragment:

After drilling of this borehole, groundwater level was not found. As the result of the drilling, the quartz veins are formed well in the baserock. Therefore, it can be expected that the open fractures may not be existed a lot. The screens were installed to know the groundwater condition in rainy season.

- Screen section: GL-40.00 - 55.00m

Borehole No.: **TD-23**
Location: Loliondo (Arusha region)
Depth of Borehole: 100.0m   Water Level: GL-13.09m

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Clay with sand
5.00 - 45.00	Sandy clay	Fluvial sediments. Fine to medium sand. Round shape.
45.00 - 50.00	Clay with Sand	Brownish clay. Quartz sand are found. Collapsing soil.
50.00 - 65.00	Sand with gravel	Fluvial sediments. Fine to medium sand. GL-56m Water strike. .
65.00 - 100.00	Gravel with sand	River bed deposit. Rounded quartzite gravel and pebble. Platy shape.

The clay layer GL-45 - 50m consist of collapsing soil. The water strikes were found in the sandy and gravely sediment layer: GL-56m, GL-65m, GL-70m and GL-75m. The screen pipes were installed at the following sections in the sediments zone.

- Screen section: GL-40.00 - 55.00m

Borehole No.: **TD-24**
Location: Basotu (Manyara region)
Depth of Borehole: 100.0m   Water Level : GL-15.9m

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Clay with coarse sand.
5.00 - 12.50	Clay	Powdery cutting sample. 2 -20 mm gravel are found in the sample. Slightly moisture.
12.50 - 30.00	Sandy clay with gravel	Clay with fine to medium sand. 2mm gravel is found. Reddish brown.
30.00 - 37.50	Clay with sand	Clay with coarse sand. Yellowish gray
37.50 - 52.00	Clay	Rounded medium sand inclusive slightly. Moisture
52.00 - 100.00	Hornblende schist	GL-60 - 70m Fractured zone. 1 -20mm rock fragment sample.

Some samples in the clay layers have moisture. Major aquifers are found in the base rock, Hornblende schist. Water strikes are found at GL-52m which is in a weathered zone, and at GL-60m and 70m which are in a fractured zone.

- Screen section: GL-40.00 - 55.00m

Borehole No. **TD-25**
Location: Orkejuloongishu (Arusha region)
Depth of Borehole: 50.0m Water Level: No water level

Depth (GL -m)	Lithology	Description
0.00 - 15.00	Sand	Un-graded medium sand, Crushed rock (boulder) with fine sand, silt
15.00 - 30.00	Tuff breccia	The gray colored sample is hard. The red colored one is able to be scratched by nails:
30.00 - 50.00	Basalt	The 20-40mm rounded rock fragment with reddish clay.

After drilling of this borehole, groundwater level was not found. This area is expected a highly permeability area since the circulation water has lost 2,500 litters twice during the drilling. Therefore, it will be difficult to develop groundwater resources in this area. In this situation, the screens were installed to know the groundwater condition in the rainy season.
- Screen section: GL-35.00 - 45.00m

Borehole No. **TD-26**
Location: Engaruka Chini (Arusha region)
Depth of Borehole: 130.0m Water Level: No water level

Depth (GL -m)	Lithology	Description
0.00 - 2.50	Overburden	Laterite
2.50 - 10.00	Fine Sand	Well graded fine sand. Small amount of gravels inclusive. The gravel sizes are 3-5mm.
10.00 - 85.00	Pyroclastic sediments	Tuffaceous sand including small amount gravels
85.00 - 130.00	Agglomerate	Mainly gray colored basaltic rock. Yellowish red to red colored pyroclastic rock.

The groundwater was not found till GL-130m even though the location of this borehole is near the river. It is expected that recovering the groundwater will be taken time, because the fine sand layers from GL-2.5m to GL-85.0m are low permeability zone. In this situation, the screens were installed to know the groundwater condition in the rainy season.
- Screen section: GL-65.00 - 72.50m, GL-70.00 - 75.00m, GL-77.50 - 82.50m, GL-85.00 - 90.00m, GL-92.50 - 97.50m, GL-100.0 - 105.0m and GL-107.5 - 112.5m,

Borehole No. **TD-27**
Location: Mfereji (Arusha region)
Depth of Borehole: 100.0m Water Level: No ground water

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Tuffaceous material
5.00 - 7.50	Tuff	Brownish gray. Cutting sample is very easy to break by finger
7.50 - 35.00	Basalt	Basaltic lava. GL-27.5m-35.0m ,autobrecciated lava
35.00 - 100.00	Agglomerate	Mainly gray rock fragment sample, The fragment is porous and angular shape.

The groundwater was not found till GL-100m. As the result, the basalt layer is expected to be high permeable layer because autobrecciated structure and the joint are found on the cutting samples. These fractured zones are not expected to be aquifer. As the result, the screens were installed at the following sections.

- Screen section: GL-60.0 - 65.0m, GL-70.0 - 75.0m, GL-77.5 - 82.5m and GL-85.0 - 90.0m,

Borehole No. **TD-28**
Location: Olmolog (Arusha region)
Depth of Borehole: 100.0m Water Level: No water level

Depth (GL -m)	Lithology	Description
0.00 - 2.50	Overburden	Clayey soil
2.50 - 25.00	Tuff breccia	Cutting sample: Tuffaceous clayey and gravely. 5 -10mm basaltic rock fragment are found. Angular shape.
25.00 - 100.00	Agglomerate	Basaltic pyroclastic rock. Matrix is tuffaceous clay. 5-10mm porous rock fragment sample. Angular shape. Fractured zone: GL-60 - 70m and GL-80 - 100m

The groundwater was not found till GL-100m. As the result, fractured zones are found at GL-60 - 70m and 80 - 100m in Agglomerate layer. In this situation, the screens were installed to know the groundwater condition in the rainy season.

- Screen section: GL-61.65 - 76.4m and GL-79.35 - 85.25m

Borehole No. **TD-29**
Location: Uwiro (Arusha region)
Depth of Borehole: 105.0m Water Level: GL-25m

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Fine sand	Rounded fine sand. Volcanic material.
5.00 - 12.50	Tuff	Hard layer and soft layer are appeared alternatively.
12.50 - 55.00	Agglomerate	Porous rock fragment sample. Water strikes are found at GL-30m and GL-45m
55.00 - 75.00	Tuff	Sandy layer and tuffaceous layer are appeared alternatively. Lamina structure is found. Water strike is found at GL-60m
75.00 - 80.00	Tuff breccia	Powdery cutting sample. Rounded basaltic rock fragment including.
80.00 - 105.00	Agglomerate	2-5mm Basaltic rock fragment is found. Porous rock. Biotite / Muscovite.

The water strikes were found in the fractured zone: GL-30m, GL-45m and GL-60m. The screen pipes were installed at the following sections in the fractured zone base on the drilling result.

- Screen section: GL-41.50 - 47.38m, GL-56.20 - 62.08m, GL-65.02 - 70.90m, GL-73,84 - 79.72m, GL-82.66 - 88.54m and GL-91.48 - 97.36m

Borehole No. **TD-30**
Location: Tingatinga (Arusha region)
Depth of Borehole: 130.0m Water Level: No water level

Depth (GL -m)	Lithology	Description
0.00 - 5.00	Overburden	Tuffaceous soil.
5.00 - 40.00	Tuff	Powdery cutting sample. 25-35mm scoria is found. Basaltic rock.
40.00 - 130.00	Agglomerate	Basaltic rock fragment sample. Angular shape. Void of the rock fragment surface is bridged by brownish clay material

After drilling of the borehole, the groundwater was not found. As the result, fractured zones are found at below GL-80 in Agglomerate layer. In this situation, the screens were installed to know the groundwater condition in the rainy season.

- Screen section: GL-82.1 - 90.93m, GL-93.9 - 99.5m, GL-102.75 - 108.65m, GL-111.6 - 117.5m and GL-120.45 - 126.35m,

6.3. Pumping Test

The pumping test was conducted after the well construction. After drilling, the sufficient groundwater to be conducted the pumping test are found at the 18 constructed wells.

6.3.1 Method of Pumping Test

The Pumping test consists of the Step drawdown test, the Constant rate pumping test and the Recovery test. The method of each test is as follows;

(1) Step Drawdown Test

The critical yield is obtained by the Step drawdown test. The Step drawdown test was conducted according to the following specifications.

Number of Steps: 5 steps.

Measurement time: Basically 120 minutes duration.

Observation time schedule for each step:

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

During the test, the pumping discharge for the Constant rate pumping test was determined by the result of the step drawdown test on a section paper

(2) Constant Rate Pumping Test

The yield of the test was decided based on the critical yield that is obtained by the Step drawdown test. The measurement interval is shows in the below table.

Time from start of pumping (minutes)			Time interval of measurement (minutes)
0	-	5	1/2
5	-	10	1
10	-	20	2
20	-	30	3
30	-	60	5
60	-	120	10
120	-	240	20
240	-	360	40
360	-	720	60
720	-	2880	120
2880 and longer			240

The discharge was recorded during the pumping test at intervals in parallel with the groundwater level measurement. During the pumping test, measured data was plotted on the section paper to check the quality of the test.

(3) Recovery Test

The test was conducted until the groundwater level has been settled, at least over 12 hours.

6.3.2 Result of Pumping Test

The aquifer constants which are Transmissivity, Storativity and Hydraulic Conductivity are calculated based on the result of the pumping test. The Cooper-Jacob method is applied for the calculation. The calculation results of 18 wells which are conducted the pumping test are shown below.

<u>Borehole TD-2 Kongogo</u>

S.W.L: GL-29.39m

Discharge (Q): 0.383 m3/min

Transmissivity (T): 1.59E-02 m2/min

Storage coefficient (S): 8.29E-01

Hydraulic conductivity (K): 4.16E-04 m/min

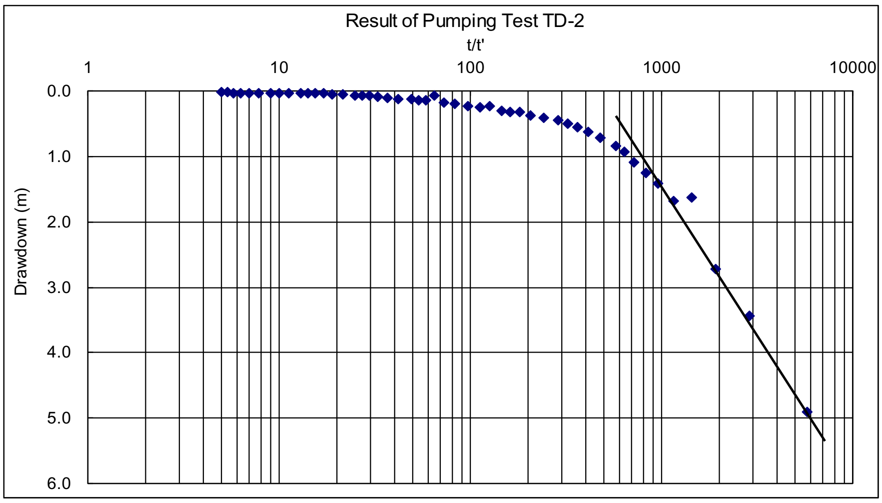


Figure 6-6 Result of Pumping Test (Kongogo)

<u>Borehole TD-3 Bubutole</u>

S.W.L: GL-28.3m

Discharge (Q): 0.06 m3/min

Transmissivity (T): 9.16E-04 m2/min

Storage coefficient (S): 1.64E-01

Hydraulic conductivity (K): 7.02E-05 m/min

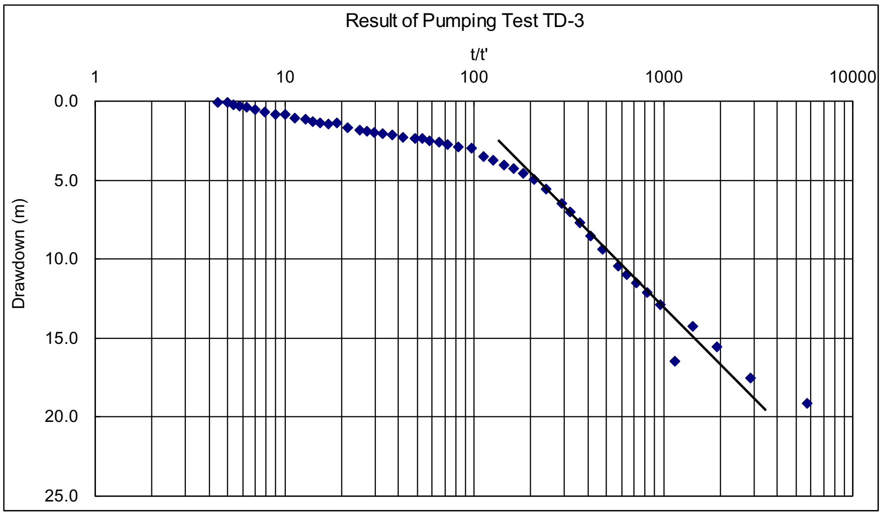


Figure 6-7 Result of Pumping Test (Bubutole)

<u>Borehole TD-4 Loo</u>

S.W.L: GL-6.47m

Critical yield (Q): 0.067m3/min

Transmissivity (T): 3.39E-03 m2/min

Storage coefficient (S): 9.48E-01

Hydraulic conductivity (K): 1.13E-04 m/min

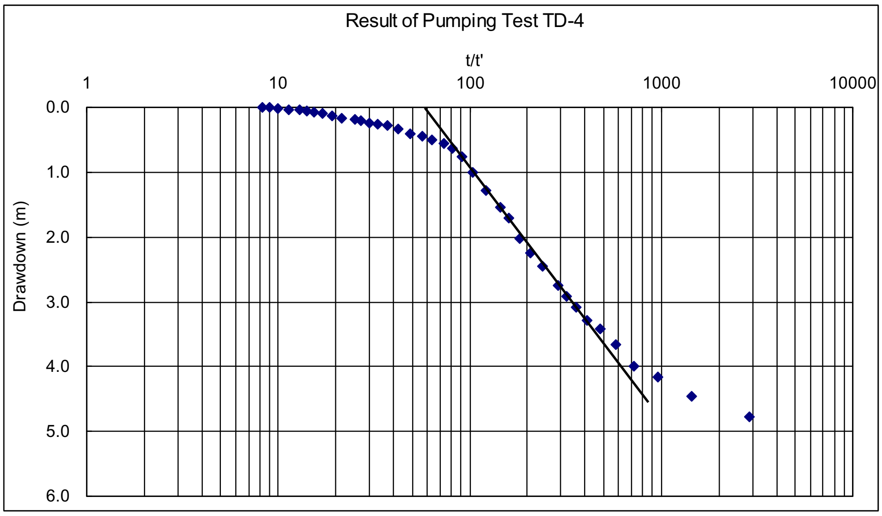


Figure 6-8 Result of Pumping Test (Loo)

Borehole TD-5 Nholi

S.W.L: GL-14.51m

Critical yield (Q): 0.88 m3/min

Transmissivity (T): 1.53E-02 m2/min

Storage coefficient (S): 6.75E-01

Hydraulic conductivity (K): 5.11E-04 m/min

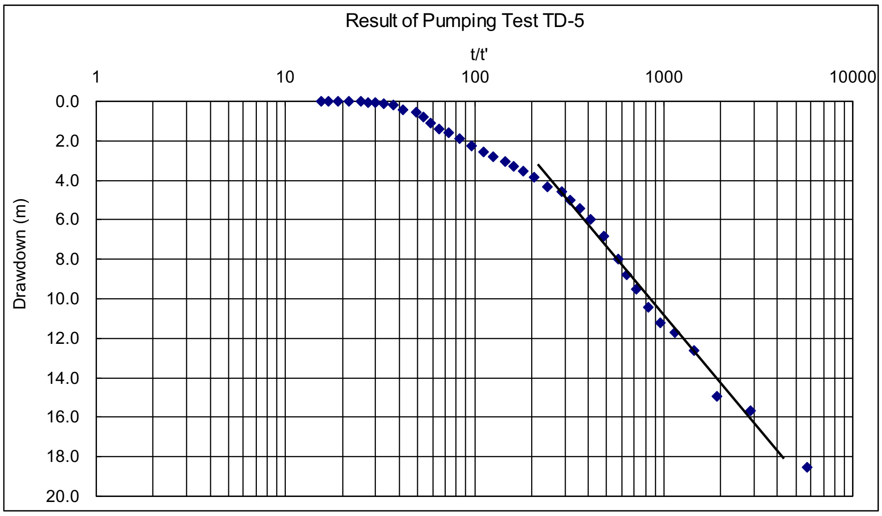


Figure 6-9 Result of Pumping Test (Nholi)

Borehole TD-7 Barmi/Seloto

S.W.L: GL-31.2m

Discharge (Q): 0.5 m3/min

Transmissivity (T): 1.76E-01 m2/min

Storage coefficient (S): 2.11E-03

Hydraulic conductivity (K): 5.99E-03 m/min

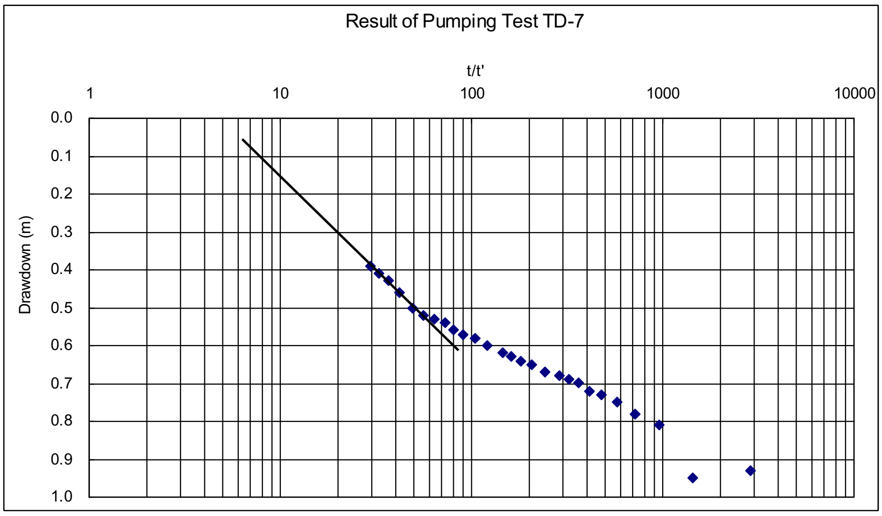


Figure 6-10 Result of Pumping Test (Barmi/Seloto)

Borehole TD-8 Ikasi

S.W.L: GL-31.75m

Critical yield (Q): 0.15 m3/min

Transmissivity (T): 1.10E-03 m2/min

Storage coefficient (S): 4.39E-02

Hydraulic conductivity (K): 1.42E-05 m/min

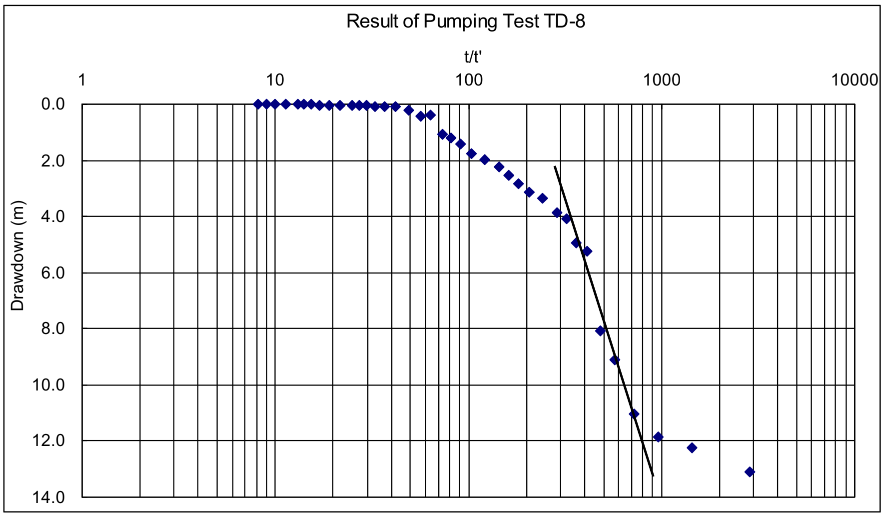


Figure 6-11 Result of Pumping Test (Ikasi)

Borehole TD-10 Hirbadaw

S.W.L: GL-31.75m

Discharge (Q): 0.017 m3/min

Transmissivity (T): 8.54E-05 m2/min

Storage coefficient (S): 1.99E-01

Hydraulic conductivity (K): 3.57E-06 m/min

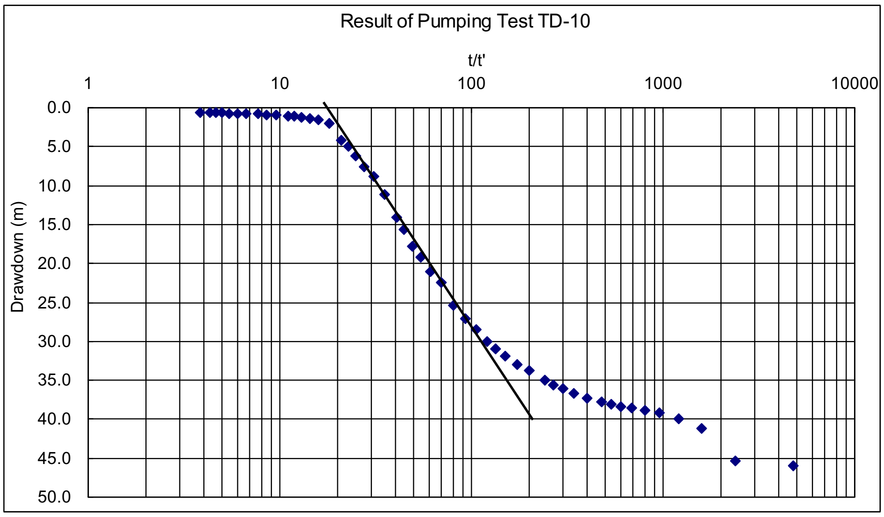


Figure 6-12 Result of Pumping Test (Hirbadaw)

Borehole TD-11 Tlawi

S.W.L: GL-11.20 m

Discharge (Q): 0.1167 m3/min

Transmissivity (T): 7.91E-04 m2/min

Storage coefficient (S): 2.85E-01

Hydraulic conductivity (K): 3.35E-05 m/min

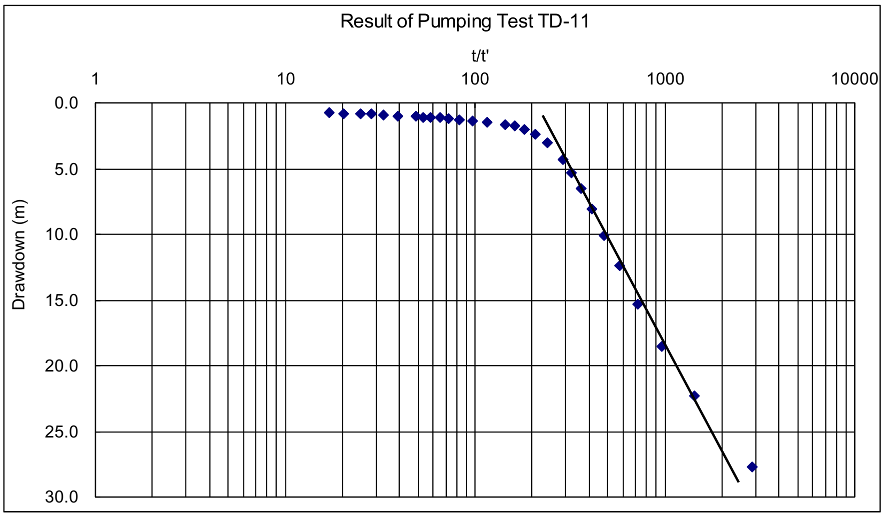


Figure 6-13 Result of Pumping Test (Tlawi)

Borehole TD-12 Misingi

S.W.L: GL-7.0m

Discharge (Q): 0.417 m3/min

Transmissivity (T): 6.36E-02 m2/min

Storage coefficient (S): 7.64E-01

Hydraulic conductivity (K): 2.15E-03 m/min

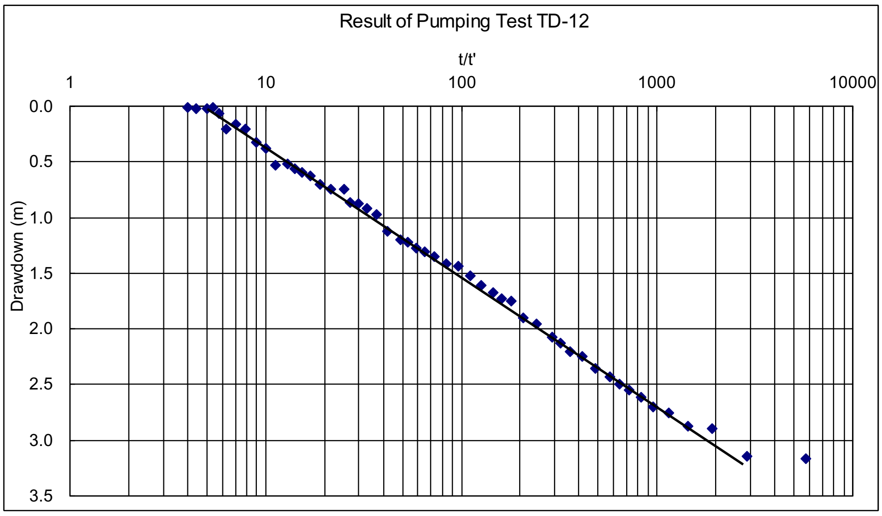


Figure 6-14 Result of Pumping Test (Misingi)

Borehole TD-13 Sepuka

S.W.L: GL-3.2m

Discharge (Q): 0.0217 m3/min

Transmissivity (T): 5.84E-04 m2/min

Storage coefficient (S): 2.34E-02

Hydraulic conductivity (K): 9.90E-05 m/min

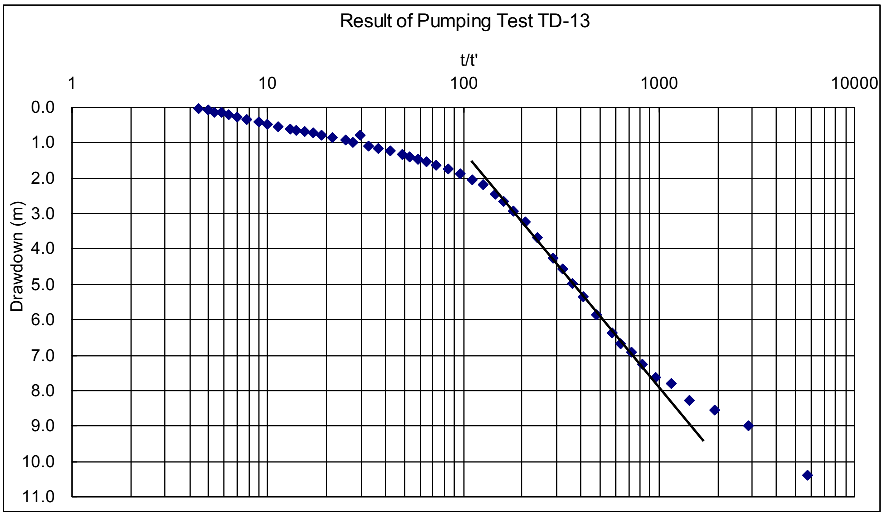


Figure 6-15 Result of Pumping Test (Sepuka)

Borehole No. TD-15 Nkongwa

S.W.L: GL-7.7m

Discharge (Q): 0.117 m3/min

Transmissivity (T): 4.27E-03 m2/min

Storage coefficient (S): 1.88E+00

Hydraulic conductivity (K): 1.81E-04 m/min

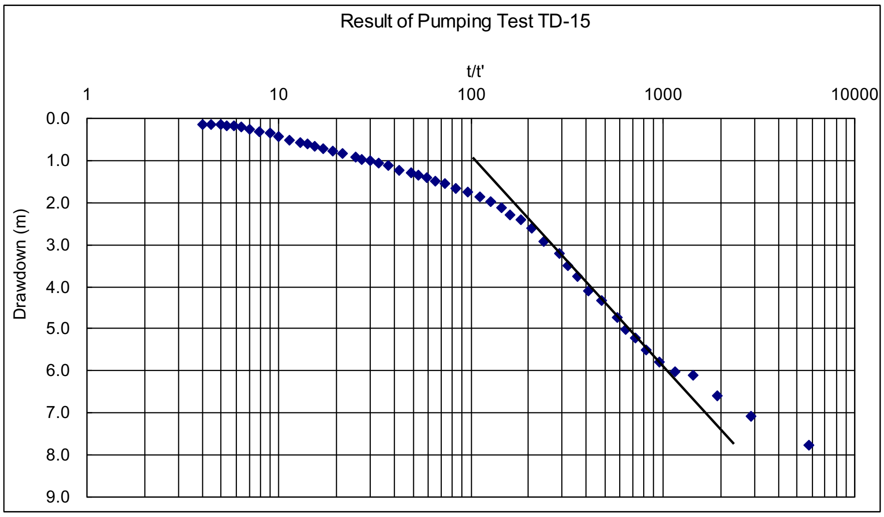


Figure.6-16 Result of Pumping Test (Nkongwa)

Borehole TD-17 Magugu

S.W.L: GL-8.38m

Discharge (Q): 0.117 m3/min

Transmissivity (T): 2.68E-03 m2/min

Storage coefficient (S): 2.20E-01

Hydraulic conductivity (K): 7.61E-05 m/min

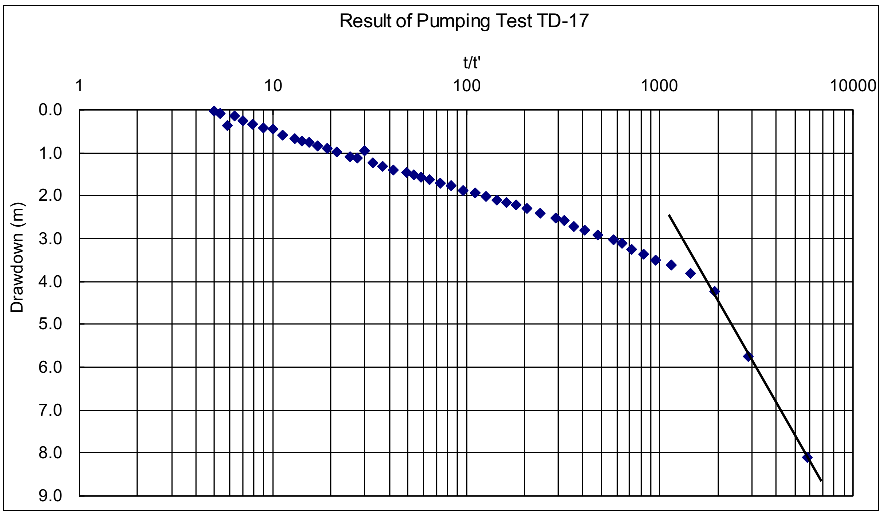


Figure 6-17 Result of Pumping Test (Magugu)

Borehole TD-19 Mekame

S.W.L: GL-35.5m

Critical yield (Q): 0.267 m3/min

Transmissivity (T): 2.71E-02 m2/min

Storage coefficient (S): 6.29E-01

Hydraulic conductivity (K): 9.87E-04 m/min

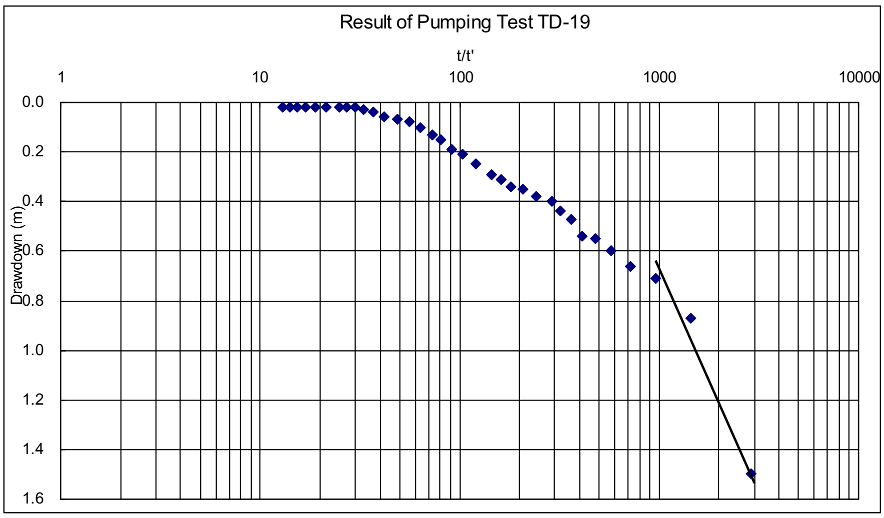


Figure 6-18 Result of Pumping Test (Makame)

Borehole TD-20 Ngofila

S.W.L: GL-4.33m

Critical yield (Q): 0.014 m3/min

Transmissivity (T): 9.61E-04 m2/min

Storage coefficient (S): 9.61E-03

Hydraulic conductivity (K): 3.20E-05 m/min

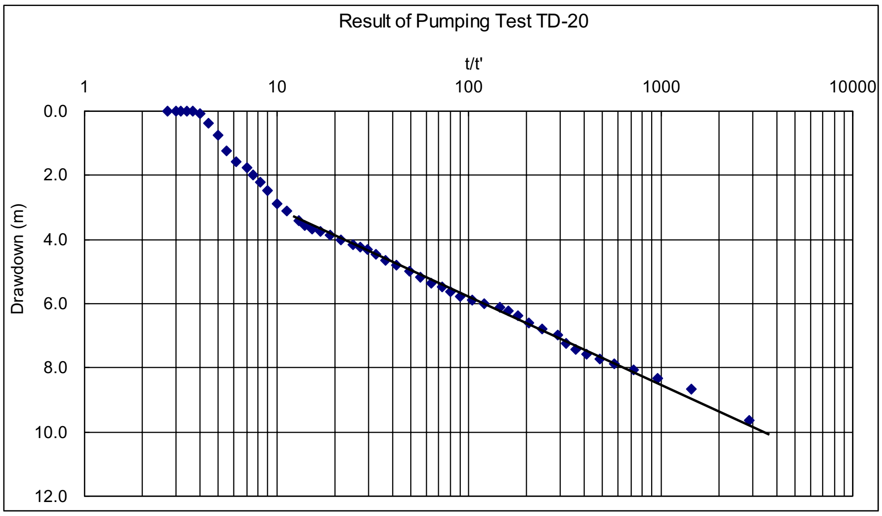


Figure 6-19 Result of Pumping Test (Ngofila)

Borehole TD-21 Mwasayi

S.W.L: GL-4.3 m

Critical yield (Q): 0.033 m3/min

Transmissivity (T): 3.14E-04 m2/min

Storage coefficient (S): 8.23E-02

Hydraulic conductivity (K): 6.67E-06 m/min

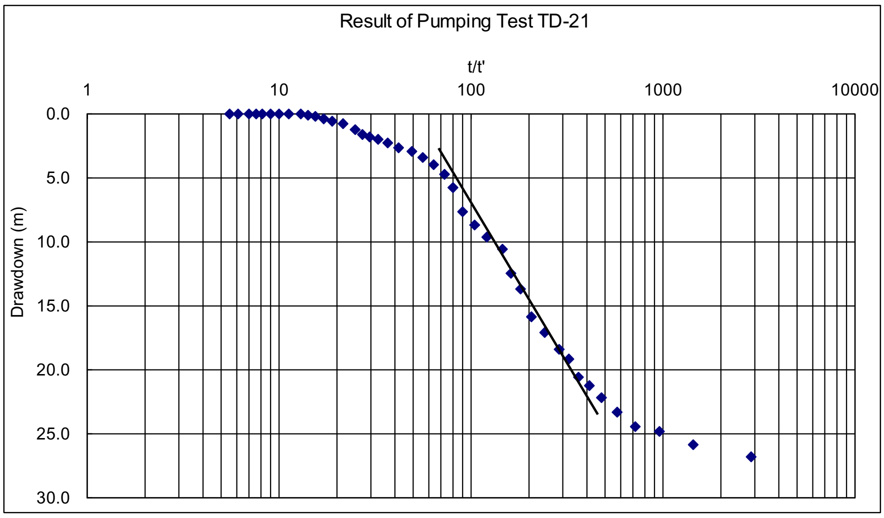


Figure.6-20 Result of Pumping Test (Mwasayi)

Borehole TD-23 Loliondo

S.W.L: GL-13.09m

Critical yield (Q): 0.014 m3/min

Transmissivity (T): 4.52E-05 m2/min

Storage coefficient (S): 2.50E-03

Hydraulic conductivity (K): 1.36E-03 m/min

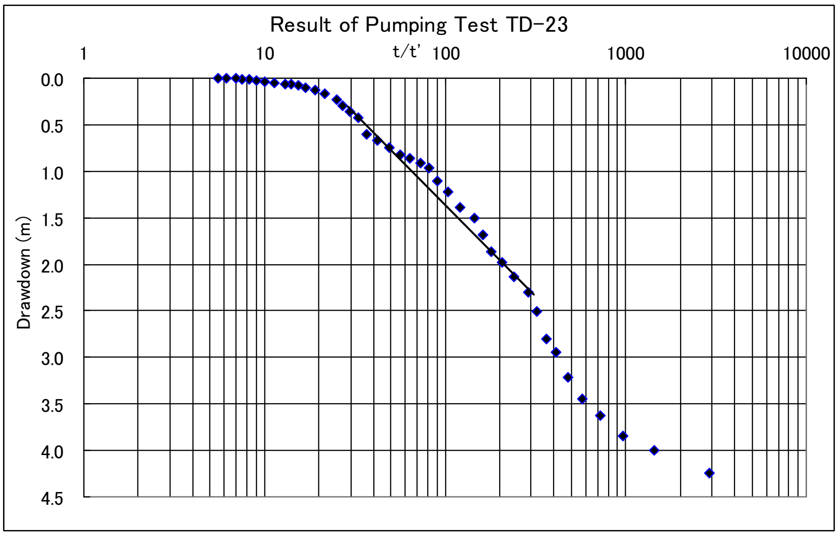


Figure 6-21 Result of Pumping Test (Loliondo)

Borehole TD-29 Uwiro

S.W.L: GL-25.5m

Critical yield (Q): 0.06 m3/min

Transmissivity (T): 2.15E-03 m2/min

Storage coefficient (S): 1.12E-01

Hydraulic conductivity (K): 3.17E-05 m/min

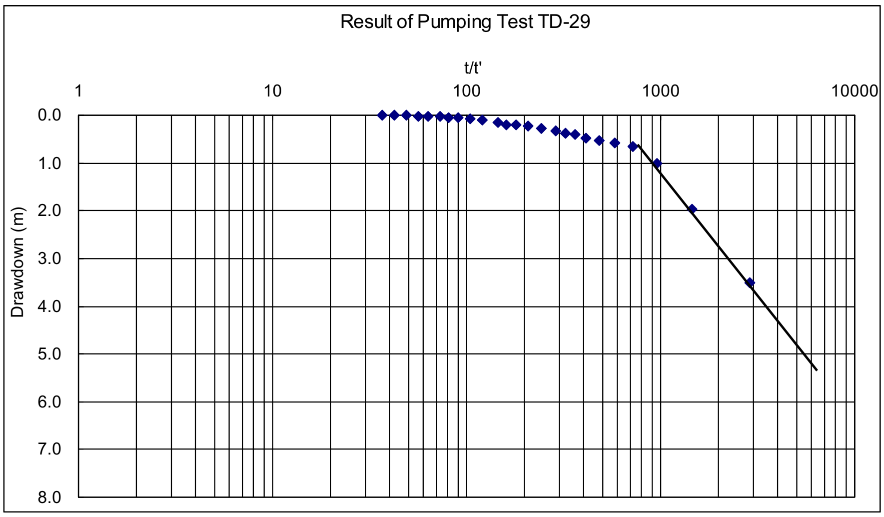


Figure 6-23 Result of Pumping Test (Uwiro)

6.3.3 Water Samples for Water Quality Test

The water sample for the water quality test was taken after implementation of the pumping test. The water samples are analyzed about same parameters of the Water Quality test for the existing wells (Refer to Chapter 7).

The result of the survey is shown in Table.6-2.

Table 6-2 Result of the Test Borehole Drilling Survey (1)

Boring No.	National BH No.	Region	District	Village	Drilling Depth (GL- m)	Well Depth (GL- m)	Presumed Target Aquifer	Aquifer					Water level (m)	Critical Yield (m^3/hour)	Water Condition	
								Nature of Aquifer	Depth (GL- m)	Hydraulic Conductivity (m/min)	Transmissivity (m^2/min)	Storativity			Electrical Conductivity (mS/m)	Fluorid (mg/l)
TD-1	654/2006	Singida	Manyoni	Lusilile	100	40	Sediments	Fractured	16.4-22.3 28.2-37.05	—	—	—	12.05	—	1,190.0	0.555
TD-2	640/2006	Dodoma	Dodoma Rural	Kongogo	105	100	Weathered/ Fractured	Fractured	57.5	4.16E-04	1.59E-02	8.29E-01	29.39	22.0	90.1	1.590
TD-3	636/2006	Dodoma	Kondoa	Bubutole	80	80	Weathered	Fractured	44, 65	7.02E-05	9.16E-04	1.64E-01	28.3	3.6	158.2	1.187
TD-4	381/2006	Dodoma	Kondoa	Loo	100	100	Fractured	Fractured	47.5-55 75	1.13E-04	3.39E-03	9.48E-01	6.47	6.0	106.3	0.049
TD-5	638/2006	Dodoma	Dodoma Rural	Nholi	105	103	Fractured	Weathered/ Fractured	80-90	5.11E-04	1.53E-02	6.75E-01	14.51	15.0	163.3	0.330
TD-6	366/2006	Manyana	Hanang	Numbeta	120	74	Weathered volcanic rock	—	—	—	—	—	N/W.L.	—	—	—
TD-7	371/2006	Manyara	Babati	Bermi/Seloto	80	78	Fault	Weathered/ Fractured	42-45 58-74	5.99E-03	1.76E-01	2.11E-03	31.2	33.1	17.3	0.560
TD-8	637/2006	Singida	Manyoni	Ikasi	120	120	Fault	Weathered/ Fractured	42-48 70-76 95-100	1.42E-05	1.10E-03	4.39E-02	30.9	15.0	261.0	0.273
TD-9	162/2006	Singida	Manyoni	Ilalo	135	135	Fractured	—	—	—	—	—	N/W.L.	—	—	—
TD-10	372/2006	Manyara	Hanang	Hirbadaw	147.5	147.5	Fractured zone	Fractured	115-130	3.57E-06	8.54E-05	1.99E-01	31.75	1.0	82.4	0.354
TD-11	370/2006	Manyara	Mbulu	Tlawi	101	100	Fractured zone	Fractured	63-86	3.35E-05	7.91E-04	2.85E-01	11.2	5.6	79.7	0.180
TD-12	651/2006	Singida	Iramba	Misingi	100	100	Fractured or weathered or sediments	Fractured	44-92	2.15E-03	6.36E-02	7.64E-01	7.0	20.4	84.8	4.650
TD-13	642/2006	Singida	Singida Rural	Sepuka	45	42	Weathered	Fractured	40	9.90E-05	5.84E-04	2.34E-02	3.2	1.6	136.6	3.138
TD-14	161/2006	Tabora	Igunga	Igogo	100	100	Weathered	—	—	—	—	—	N/W.L.	—	—	—
TD-15	650/2006	Tabora	Uyui	Nkongwa	60	60	Sediment or weathered	Weathered/ Fractured	30-37 47-58	1.81E-04	4.27E-03	1.88E+00	7.7	4.7	384.0	1.270
TD-16	644/2006	Tabora	Igunga	Kininginila	80	80	Sediments	Sediments	62-68	—	—	—	40.5	—	1,600.0	—
TD-17	652/2006	Manyara	Babati	Mapea	80	80	Sediments	Sediments/ Weathered	27, 40, 72	7.61E-05	2.68E-03	2.20E-01	8.38	4.7	195.1	7.910
TD-18	385/2006	Dodoma	Kondoa	Masange	70	69	Fractured	—	—	—	—	—	68.9	—	—	—
TD-19	635/2006	Manyara	Kiteto	Makeme	75	72	Fractured	Fractured	44-50, 68	9.87E-04	2.71E-02	6.29E-01	35.5	16.0	1090.0	0.991
TD-20	653/2007	Shinyanga	Kishapu	Ngofila	75	75	Sediments	Sediments	50	3.20E-05	9.61E-04	9.61E-03	4.33	0.8	687.0	34.950

Table 6-2 Result of the Test Borehole Drilling Survey (2)

Boring No.	National BH No.	Region	District	Village	Drilling Depth (GL- m)	Well Depth (GL- m)	Presumed Target Aquifer	Aquifer					Water level (m)	Critical Yield (m^3/hour)	Water Condition	
								Nature of Aquifer	Depth (GL- m)	Hydraulic Conductivity (m/min)	Transmissivity (m^2/min)	Storativity			Electrical Conductivity (mS/m)	Fluorid (mg/l)
TD-21	522/2007	Shinyanga	Maswa	Mwasayi	70	70	Fractured or weathered	Weathered/ Fractured	35	6.67E-06	3.14E-04	8.20E-02	4.3	2.4	414.0	1.410
TD-22	523/2007	Shinyanga	Meatu	Mwangudo	100	62	Fractured or weathered	—	—	—	—	—	N/W.L.	—	685.0	26.500
TD-23	526/2007	Arusha	Ngorongoro	Loliondo	100	75	Fractured or weathered	Fractured	65, 70, 80, 85	1.36E-03	4.52E-05	2.50E-03	13.09	4.0		
TD-24	527/2007	Manyara	Hanang	Bassotu	100	100	Fractured	Sediment	52, 60, 70	—	—	—	—	—	—	—
TD-25	520/2007	Arusha	Longido	Orkejuloongishu	50	45	Fault	—	—	—	—	—	N/W.L.	—	—	—
TD-26	518/2007	Arusha	Monduli	Engaruka Chini	130	115	Sediment	—	—	—	—	—	N/W.L.	—	—	—
TD-27	519/2007	Arusha	Monduli	Mfereji	100	98	Fractured or weathered	—	—	—	—	—	N/W.L.	—	—	—
TD-28	524/2007	Arusha	Longido	Olmolog	100	90	Fractured or weathered	—	—	—	—	—	N/W.L.	—	—	—
TD-29	521/2007	Arusha	Arumeru	Uwiro	105	100	Fractured	Weathered/ Fractured	30,45,60	3.17E-05	2.15E-03	1.12E-01	25.5	8.6	95.3	15.390
TD-30	525/2007	Arusha	Longido	Tingatinga	130	129	Sediment	—	—	—	—	—	N/W.L.	—	—	—

Chapter 7
Water Quality Survey

CHAPTER 7 WATER QUALITY SURVEY

7.1 Introduction

Interviews were conducted with the water engineers of the six regions in the Internal Drainage Basin (IDB), where the survey was conducted, resulting in information that suggests the existence of a large area with very high fluoride levels at water sources. However, the distribution of fluoride levels at those sources throughout the entire project area has not yet been clarified. Moreover, the origin of fluoride or water pollution at water sources with other pollutants is not yet fully understood either. Thus, the water quality survey was carried out in this study with the aim to elucidate the following points:

i) Comprehend the overall picture of fluoride distribution
ii) Clarify the origin of high fluoride supply in water sources
iii) Comprehend the actual state of pollution of water sources

Table 7.1 gives the details of the surveys that were implemented in order to achieve each of the above items.

Table 7-1 Contents of Water Quality Survey

Purpose	Survey method	Water quality survey points
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 the entire convergence area.
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 level of fluoride in order to clarify the relationship between the various minerals and the fluoride level 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.

7.2 Methodology

7.2.1 Collecting of Existing Water Quality Data

The existing data were collected of the water quality survey in IDB in the first field survey to identify the general fluoride pollution conditions and formulate a plan for simplified water quality tests (on 200 villages) in the Second Field Survey. Table 7-2 shows the origins of the data that was collected, water quality analysis items and availability of water quality data for water sources stored at each of the regional offices.

Table 7-2 Outline of Existing Data of Water Quality

Region	Collected data: Origin	Collected data: Water Quality Analysis Items	Availability of Data at Offices
Arusha (Manyara)	Arusha Region Water Master Plan (2000) supported by UNDP	turbidity, pH, EC, TDS, alkalinity, hardness, Ca, Mg, Fe, Mn, NO_3, NO_2, SO_4, Cl, F, $KMnO_4$	Available as digital files
Shinyanga	Database established by Shinyanga sub-basin office	EC, F	Available as digital files that form a database
Singida	The Study on the Groundwater Development for Hanang, Singida Rural, Manyoni and Igunga Districts by JICA (1998)	pH, EC, NO_3, NO_2, NH_4, F, colon bacillus	Paper files are available only for water quality analysis results, but no digital files
	The Basic Design Study on the Project for the Rural Water Supply Project in Hanang, Singida Rural, Manyoni and Igunga Districts by JICA (2001)	pH, EC, F	
Tabora	Tabora Region Water Master Plan (1979) supported by International Bank	turbidity, pH, EC, TDS, alkalinity, hardness, Si, Ca, Mg, Fe, Mn, NO_3, NH_4, SO_4, Cl, F, $KMnO_4$	Paper files are available only for water quality analysis results, but no digital files
	Water quality test results for B.H in IDB stored by Tabora sub-basin office	Turbidity, pH, EC, Hardness, NO_3,	
Dodoma	Water quality test results for B.H in IDB stored by Dodoma sub-basin office	pH, EC, TDS, alkalinity, hardness, Ca, K, Mg, NO_3, NO_2, SO_4, Cl, F	Paper files are available only for water quality analysis results, but no digital files

Figure 7-1 and Table 7-3 shows the distribution of water sources that were included in a water quality survey in and around the study area according to the existing data.

Table 7-3 Number of Water Sources for Water Quality Survey

Water Source	Arusha	Manyala	Singida	Shinyanga	Tabora
B.H	13	19	97	31	8
D.W, S.W	22	36	41	2587	4
Water Hole	3	7	83	0	21
River	43	46	2	0	0
Lake, Spring	71	49	6	0	0
Dam	4	2	10	0	17
Unknown Source	5	3	1	0	0
Total	160	162	240	2618	50

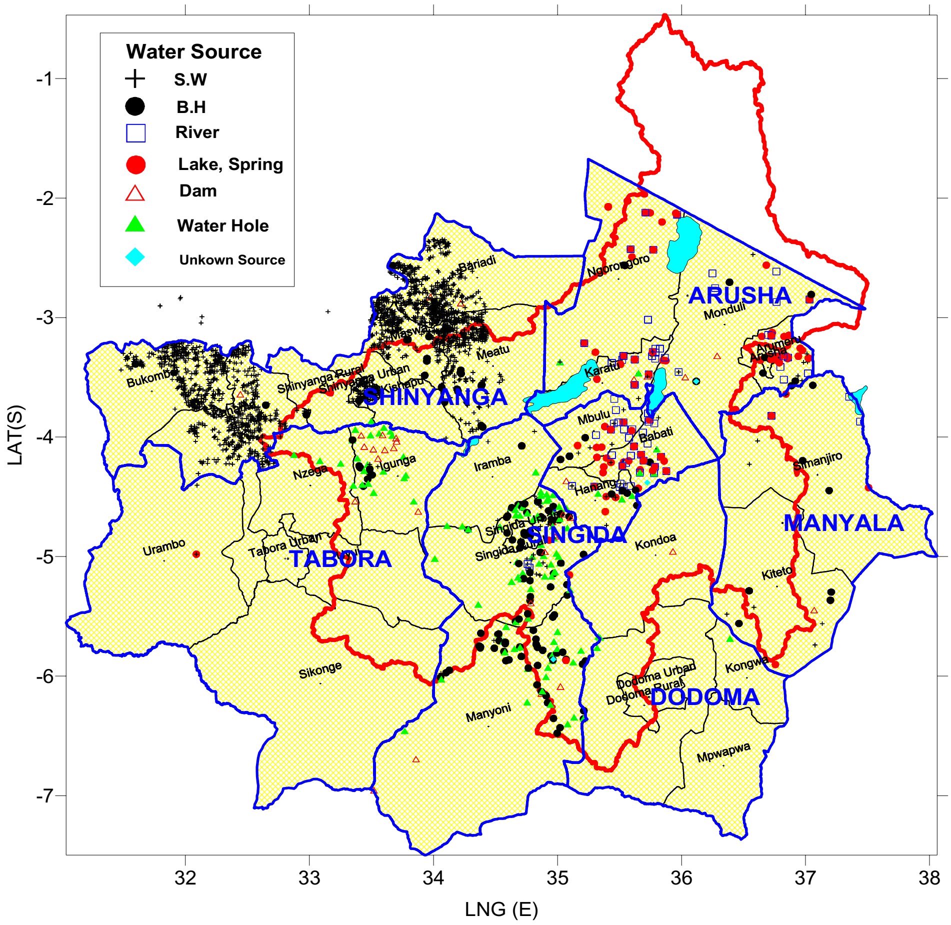


Figure 7-1 Distribution of Water Sources in Water Quality Survey

The water quality data available for water sources in the following districts in the study area was insufficient:

1. Arusha — Insufficient water quality survey data for B.H.
2. Manyala — Insufficient water quality survey data for Simanjiro and Kiteto Districts in the Study Area
3. Singida — Insufficient water quality survey data for Iramba Districts
4. Shinyanga — Insufficient water quality survey data for water sources rather than shallow wells
5. Tabora — Insufficient water quality survey data for Uyui and Nzega Districts in the Study Area
6. Dodoma — Insufficient water quality survey data for Dodoma rural and Kondoa Districts in the Study Area

7.2.2 Simplified Water Quality Test

(1) Methodology

The simplified water quality test was carried out two times during this study. The first simplified water quality test was carried out from February to March 2006. The second simplified water quality test was carried out on August 2006. Two hundred and sixty-four samples (183 villages) and 317 samples (266 villages) were selected by first time and second time simplified water quality tests. The following water quality items were measured in the field by simplified water quality measuring instruments and field kits.

Measurement by simplified water quality measuring 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.

Meanwhile, a water quality survey was conducted in the inventory survey of this study using the same water quality items as the simplified water quality test.

Figure 7-2 Simplified Water Quality Survey on Site

On-site observation of water quality for water temperature, EC, pH, ORP, fluorine, iron, manganese, arsenic, nitrate ion, ammonia ion, sulfide ion, and coliform bacteria was carried out by the methods given below. The water sources where high fluoride levels were observed using a field kit, water samples were collected and brought into the JICA office in Singida. The water samples were then re-analyzed using a fluorine meter.

Table 7-4 Water Quality Items and Analytical Methods for Simplified Water Quality Test

Item	Analytical Method	Measurement Range	Remark
Water Temperature	Thermometer	0 ~ 99 Celsius	Accuracy: 0.1 Celsius
pH	pH meter	0 ~ 14	Accuracy: 0.01 pH
EC	EC meter	0 ~ 19.99 s/m	Error: 0.5%
ORP	ORP meter	0 ~ ±1999 mV	Error: ±2 mV
Sulfide ion	Pack test	0.1 ~ 5 mg S/l	Sulfate ion not detected by this method
Fluoride	Pack test	0 ~ 8 mg F/l	Large error at high level (more than 3 mg F/l)
	Fluorine meter	0.1 ~ 199.9 mg F/l	Error: ±5 %
Arsenic	Hironaka-type field kit	0.00 ~ 1.00 mg As/l	Large error at low level (0.01~ 0.05 mg As/l)
Ammonium	Pack test	0.2 ~ 10 mg NH_4/l	Influenced by a small content of iron, etc.
Nitrate	Pack test	1 ~ 45 mg NO_3/l	Not influenced by coexisting materials
Iron	Pack test	0.05 ~ 2 mg Fe/l	Not influenced by coexisting materials
Manganese	Pack test	0.5 ~ 20 mg Mn/l	Not influenced by coexisting materials
Coliform	Pack test		

(2) Survey Location

The number of villages for the simplified water quality tests was planned at about 200, but actually 183 villages and 266 villages were selected for the first and second simplified water quality tests considering availability of water source conditions. Moreover, the survey focused on the areas where there is not enough existing data of water quality data and where the effects of fluorine contamination are presumed to be higher from other information. The first simplified water quality test was carried out from February to March 2006. The second simplified water quality test was carried out on August 2006. The number of the surveyed villages and water sources were as shown in Table 7-5 and 7-6. Figure 7-3 shows the locations of each type of water source for the first (see a.) and second (see b.) simplified water quality tests.

Table 7-5 Selected Villages and Water Sources for the First Simplified Water Quality Test

Region	No. Surveyed Villages	Borehole		Dug well, Shallow well, Waterhole		Dam, Pond, River and Rain		Spring		Tatal	
		No. Sample	%	No. Sample	%	No. Sample	%	No. Sample	%	No. Sample	%
Arusha	38	8	16	3	6	12	24	28	55	51	100
Manyara	33	6	14	17	40	4	9	16	37	43	100
Dodoma	18	3	10	17	57	3	10	7	23	30	100
Tabora	20	1	4	12	46	11	42	2	8	26	100
Shinyanga	34	1	2	21	39	28	52	4	7	54	100
Singida	40	5	8	29	48	16	27	10	17	60	100
Total	183	24	9	99	38	74	28	67	25	264	100

Table 7-6 Selected Villages and Water Sources for the Second Simplified Water Quality Test

Region	No. Surveyed Villages	Borehole		Dug well, Shallow well, Waterhole		Dam, Pond, River and Rain		Spring		Tatal	
		No. Sample	%	No. Sample	%	No. Sample	%	No. Sample	%	No. Sample	%
Arusha	47	13	23	2	4	12	21	29	52	56	100
Manyara	35	8	18	16	36	4	9	16	36	44	100
Dodoma	22	4	13	17	57	2	7	7	23	30	100
Tabora	33	11	31	14	40	9	26	1	3	35	100
Shinyanga	57	16	23	28	39	23	32	4	6	71	100
Singida	72	36	44	27	33	10	12	8	10	81	100
Total	266	88	28	104	33	60	19	65	21	317	100

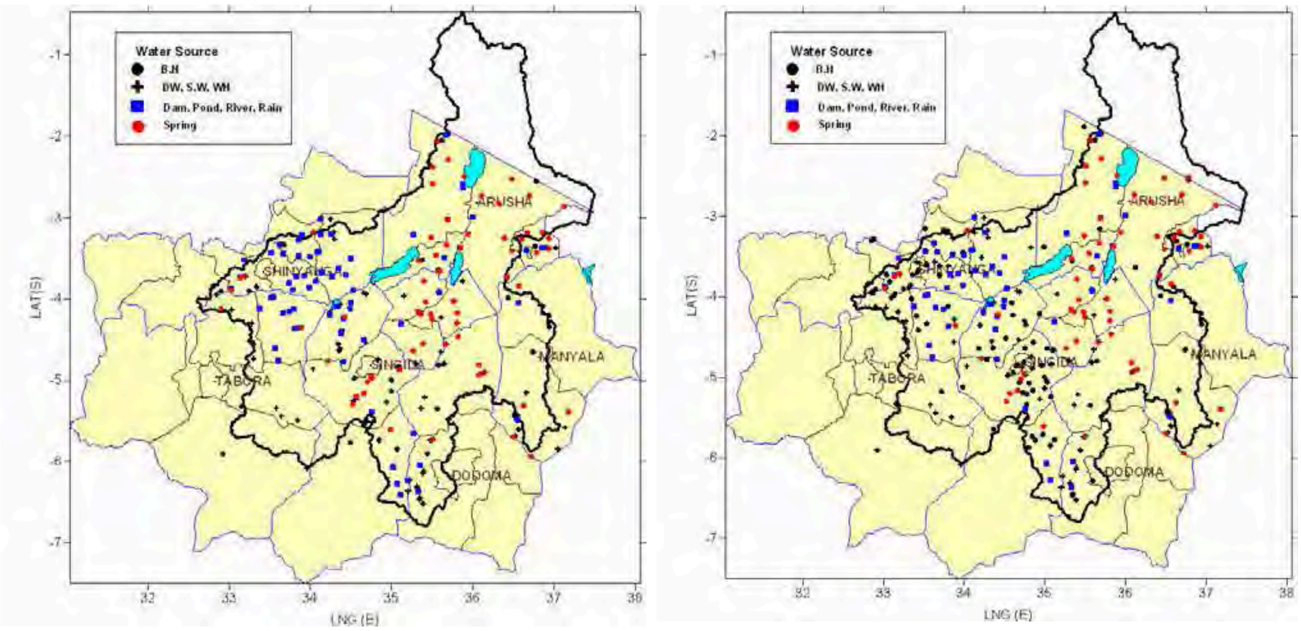


Figure 7-3 Distribution of Survey Points for Simplified Water Quality Test

a. First simplified water quality test, b. Second simplified water quality test

7.2.3 Laboratory Test of Water Quality

(1) Methodology

A laboratory test of water quality was conducted in order to evaluate the water resources in IDB from the viewpoint of groundwater suitability as drinking water, availability of other water sources, water treatment methods and so on. Water quality parameters for the test (see Table 7-7) included additional parameters other than those used for the provisional water quality standards related to drinking water in Tanzania.

Table 7-7 Water Quality Parameters for Laboratory Test

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 [Totalsolids - Total dissolved solids]
*5: Total filterable residue is equal to Total dissolved solids (TDS).
[shaded box] Items adopted for water quality evaluation.

The samples of existing water resources were collected during the second simplified water quality test. The samples of test wells were collected from October 2006 to September 2007. Cyanide (CN) and heavy metals such as iron (Fe), manganese (Mn), lead (Pb), zinc (Zn), mercury (Hg), chromium (Cr), copper (Cu) and so on change before the actual analysis. To prevent this from happening, adequate treatment should be implemented; these processes are shown in **Figure 7-4**.

The water samples were brought into a laboratory in Dar es Salaam in Tanzania as soon as possible after sampling. The analytical methods for the laboratory test of water quality are shown in **Table 7-8**.

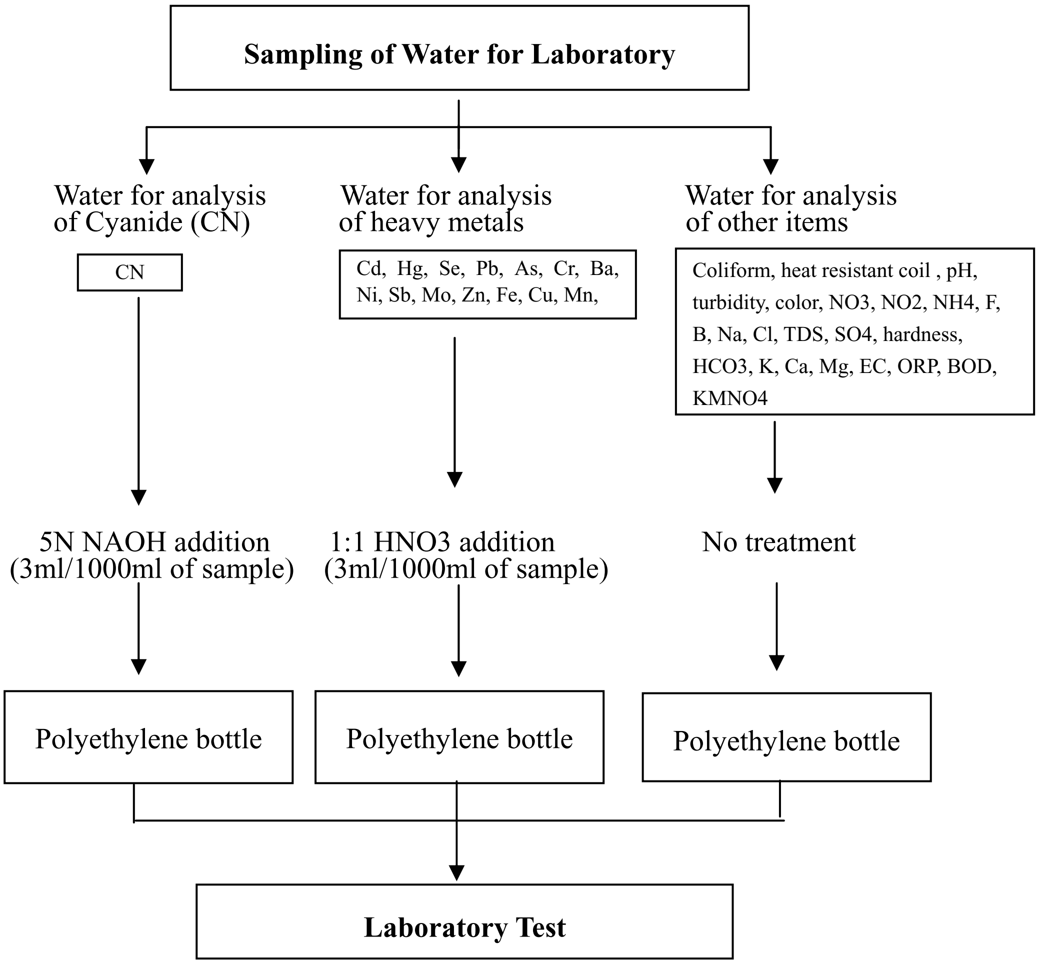


Figure 7-4   Treatment Processes before Laboratory Test

Table 7-8 Items and Analytical Methods for Laboratory Test of Water Quality

No.	Item	Analytical Method	Detection limits	Unit
1	Bacteria	Membrane Filtration	0	CFU/100ml
2	Escherichia coli	Membrane Filtration	0	CFU/100ml
3	Lead (Pb)	AAS	0.01	mg/l
4	Arsenic (As)	AAS	0.05	μg/l
5	Selenium (Se)	AAS	0.05	μg/l
6	Chromium (Cr)	AAS	0.01	mg/l
7	Cyanide (CN)	Spectrophotometer DR/2010	0 - 0.2	mg/l
8	Antimony (Sb)	AAS	0.05	μg/l
9	Cadmium (Ca)	AAS	0.001	mg/l
10	Barium (Ba)	Spectrophotometer DR/2010	0-100	mg/l
11	Mercury (T-Hg)	AAS	0.05	μg/l
12	Fluoride (F)	Ion SpecificEletrode	0.001	mg/l
13	Nitrate (NO_3)	Spectrophotometer DR/2010	0-30	mg/l
14	Nitrite Nitrogen (NO_2)	Spectrophotometer DR/2010	0-0.300	mg/l
15	Ammonia-Nitrogen (NH3)	Spectrophotometer DR/2010	0-2.50	mg/l
16	Color	Spectrophotometer DR/2010	0-509	TCU
17	Turbidity	Spectrophotometer DR/2010	0-205	NTU
18	pH	Potentiometric (PH meter)		
19	Total Dissolved Solids (TDS)	Potentiometric (TDS meter)	0.01	mg/l
20	Total Hardness	Titrimetric	1	mg/l
21	Calcium (Ca)	AAS/Titration	0.01	mg/l
22	Magnesium (Mg)	AAS	0.01	mg/l
23	Sodium (Na)	AAS	0.01	mg/l
24	Potassium (K)	AAS	0.01	mg/l
25	Bicarbonate (HCO_3^{2-})	Titrimetric	1	mg/l
26	Sulfate (SO_4^{2-})	Spectrophotometer DR/2010	0-70.00	mg/l
27	Chloride (Cl^-)	Titrimetric	1	mg/l
28	Iron (Fe)	Spectrophotometer DR/2010	0-3.00	mg/l
29	Manganese (Mn)	Spectrophotometer DR/2010	0-20.0	mg/l
30	Copper (Cu)	AAS	0.01	mg/l
31	Zinc (Zn)	AAS	0.01	mg/l
32	Biochemical Oxygen Demand (BOD)	BOD TRACK		mg/l
33	Oxygen abs KMnO4	Reactor digestion method	0-1500	mg/l
34	Boron (B)	Spectrophotometer DR/2010	0-1.50	mg/l
35	Molybdenum (Mo)	AAS	5	mg/l
36	Nickel (Ni)	AAS	0.01	mg/l
37	Electrical Conductivity (EC)	Conductivity Meter	0.01	μS/cm
38	Oxidation-reduction potential (ORP)	ORP meter		mV

AAS: Atomic Absorption Spectophotometer

(2) Water Sampling Location

Table 7-9 shows the number of the surveyed villages and existing water sources for laboratory tests. Figure 7-5 shows the location of sampling of existing water sources for laboratory testing.

Table 7-9 Selected Villages and Existing Water Sources for Laboratory Test of Water Quality

Region	Borehole		Dug well, Shallow well, Waterhole		Dam, Pond, River and Rain		Spring		Test Drilling Well	
	No. Sample	%	No. Sample	%	No. Sample	%	No. Sample	%	No. Sample	%
Arusha	9	11	2	10	3	33	16	64	1	6
Manyara	15	18	1	5	0	0	4	16	5	28
Dodoma	19	22	2	10	0	0	3	12	4	22
Tabora	4	5	9	45	4	44	1	4	1	6
Shinyanga	12	14	4	20	1	11	0	0	3	17
Singida	26	31	2	10	1	11	1	4	4	22
Total	85	100	20	100	9	100	25	100	18	100

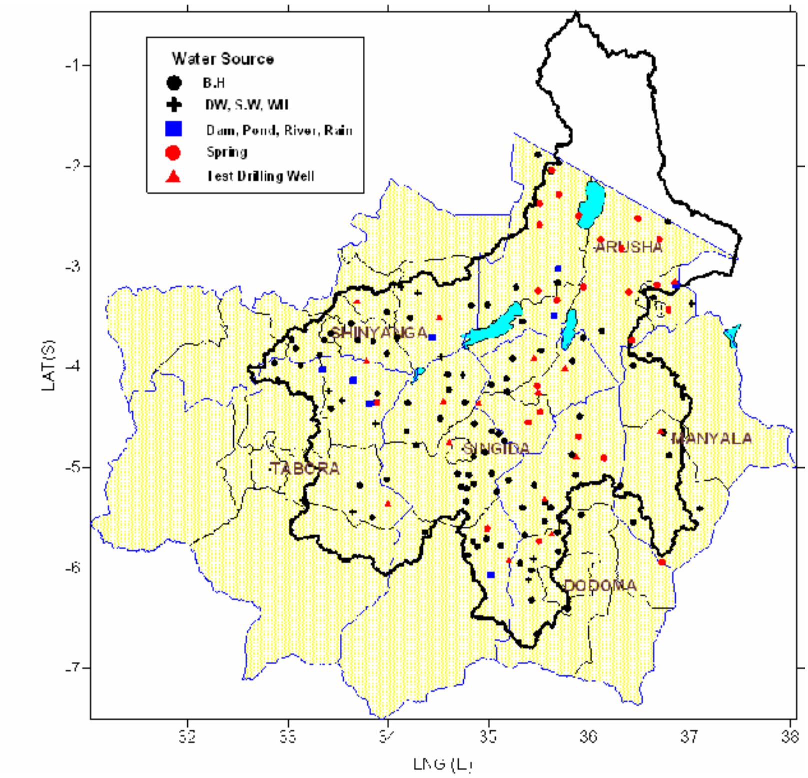


Figure 7-5 Water Sampling Locations for Laboratory Test of Water Quality

7.3 Survey Results

The results of the first and second simplified water quality tests are tabulated in Databook-B. The results of existing water sources and test drilling well by laboratory tests are tabulated in Databook-B.

7.3.1 Water Quality of Surface Water

(1) Water Quality in the Major Lakes

Table 7-10 shows the water quality in the major lakes around IDB. The fluoride levels in the water of the lakes in the study area (the Tanzanian side of IDB) are within the range of 0.3 – 966mg/l, with Lake Natron having the highest level. Lake Magadi located in the Kenyan side of the same IDB is reported to have the highest fluoride level (1,550mg/l) in Africa. The characteristics of the lakes in the study area are that many of them are shallow lakes with a maximum water depth of 3m or less, as exemplified by Lakes Natron, Manyara and Eyasi, and that many are alkaline salt lakes with large quantities of sodium and potassium in their water.

Table 7-10 Water Quality in Lakes around the Study Area

Name	Area	Depth	Vol	Altitude	pH	Alkali	Salinity	Na	K	Ca	Mg	Cl	SO4	F	SiO2
	km2	m	Km3	m		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Turkana	7,600	**75**	251	400	9.5	23	2	48	1	0	0	21	1	**8.6**	0.5
								767	22	5	2	440	37		22.0
Baringo	129	**8**	-	965	8.8	4	-	95	13	12	3	25	20	-	23.5
Bogoria	34	-	-	963	10.6	965	-	28,400	387	-	-	6,390	216	**1,060**	260.0
Nakuru	45	**3**	-	1,758	-	-	-	79	2	-	-	9	1	-	0.6
Naivasha	195	**18**	-	1,884	8.1	2	-	24	12	16	5	7	5	**1.0**	24.6
Magadi	104	-	-	575	11.0	3,170	-	132,000	2,280	-	-	84,400	2,190	**1,550**	1,055.0
							-	-	-	-	-	-	-	**437**	-
Natron	900	<3	-	610	10.0	2,096	-	62,700	1,080	-	-	18,300	4,420	**966**	155.0
Manyara	470	**3**	-	960	9.8	806	-	2,500	8	10	1	1,173	230	-	10.0
							-	21,500	94		30	8,670	1,056	**-**	19.0
							-	-	-	-	-	-	2,280	**-**	-
Eyasi	1,050	<3	-	1,030	-	-	-	4,480	55	-	4	4,360	340	-	-
Basutu	-	<3	-	-	8.4	-	-	91	-	-	-	-	-	**2.2**	-
Duluti	-	<3	-	-	9.2	-	-	66	-	-	-	-	-	**3.0**	-
Tlawi	-	<3	-	-	6.6	-	-	107	-	-	-	-	-	**0.4**	-
Basutoghang	-	<3	-	-	7.2	-	-	54	-	-	-	-	-	**0.3**	-
Kindai		<3			8.5			1,236						**1.3**	
Singid		<3			9.0			590						**1.1**	
Victoria	68,500	**90**	2,700	1,134	8.0	1	0	10	3	5	4	4	5	**0.3**	17.1
Kyoga	2,047	-	-	1,037	-	-	-	28	7	14	7	7	5	**0.5**	30.0
Albert	5,900	**55**	150	617	8.9	7	1	4	2	1	3	1	1	-	0.1
								25	10	2	8	6	2	**-**	-
George	258	**4**	-	914	8.7	2	0	1	0	1	1	0	0	-	0.7
								14	3	12	8	6	3	**-**	-
Edward	2,200	**11**	78	914	8.8	10	1	5	2	1	4	1	1	-	0.5
								23	11	2	10	5	2	**-**	-
Kivu	2,250	**485**	570	1,163	9.3	16	1	6	2	1	7	1	0	**1.9**	0.6
								20	10	1	14	6	1		
Tanganyika	33,500	**1,470**	18,900	773	8.5	7	1	3	1	1	4	1	0	**1.1**	-
								24	7	2	14	5	0	**-**	-
Rukwa	2,716	**10**	-	793	-	-	-	41	2	-	-	9	1	-	0.6
Malawi	25,000	**770**	6,150	475	8.6	2	0	1	0	1	0	0	0	-	0.5
								21	4	12	5	3	1	**-**	-

(shaded) Within IDB

(2) Water Quality of Surface Water (in Rivers, Dams, Ponds, Springs, etc.)

Quality of surface water (in rivers, dams, ponds and springs) in the study area was surveyed at 175 points in rivers, dams and ponds and 154 points in springs with collected available data, the simplified water quality test and the inventory survey. Table 7-11 shows the averages and frequencies of occurrence of fluoride levels (F), electric conductance (EC) and pH of the surface water. Figures 7-6, 7-7 and 7-8 show the distribution patterns of fluoride levels (F), electric conductivity (EC) and pH, respectively, of the surface water in the study area.

Among the six regions in which this survey was conducted, the highest fluoride level in the rivers, dams and ponds was observed in Shinyanga Region (average: 2.4mg/l) and that in springs was observed in Arusha Region (average: 2.6mg/l). At the local level, Ayahata Spring in Endaberg Village, Babati District, Arusha Region, had the highest level of 66mg/l, followed by Kituma River in Lositete Village, Karatu District, Arusha Region, of 44mg/l. Water in seven percent of all the rivers, dams and ponds and 12 percent of all the springs exceeded the water quality standard for fluoride in drinking water in Tanzania (fluoride level of 4mg/l or less).

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

Unlike EC, the pH of spring water was lower than that of water in the rivers, dams and ponds. The Tanzanian standard for pH of drinking water is pH 6.5 – 9.2. Water with pH 6 or less was found in four percent of the rivers, dams and ponds and two percent of the springs. Water with pH 9 or larger was found in six percent of the rivers, dams and ponds and one percent of the springs.

Table 7-11 Concentrations and Frequency of Occurrence for Fluoride, EC and pH in Surface Water in IDB

Fluorid

Region	Dam, Pond and River				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

Unit: mg/l

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

EC

Region	Dam, Pond and River				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

Unit: mS/m

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

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

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

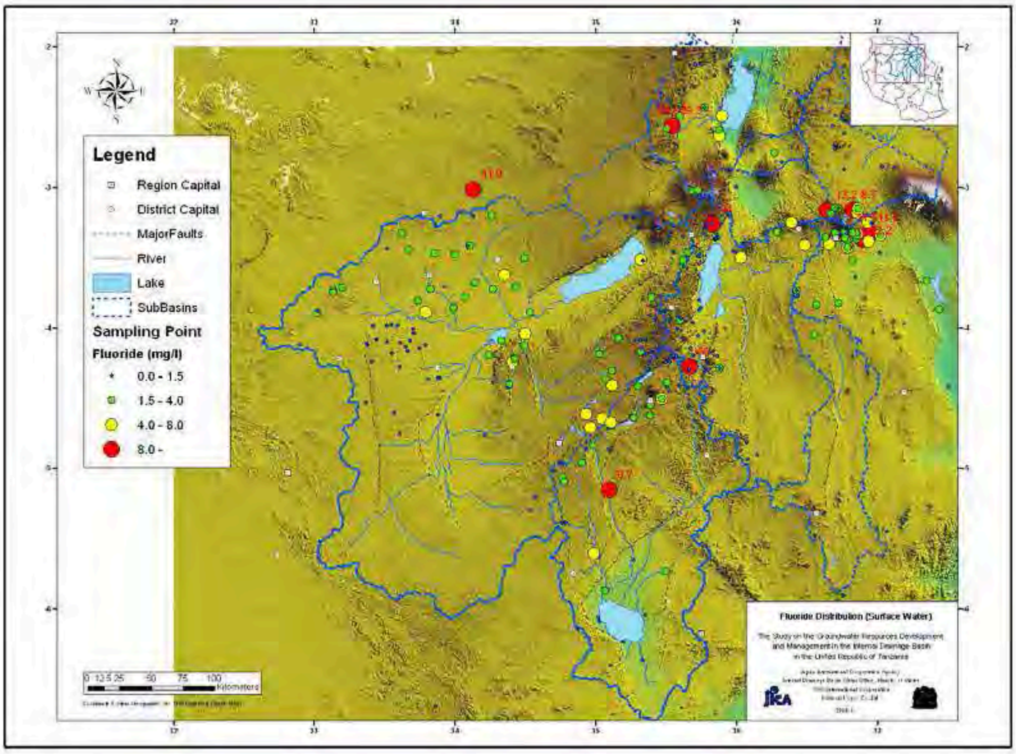


Figure 7-6 Distribution of F in the Surface Water in IDB

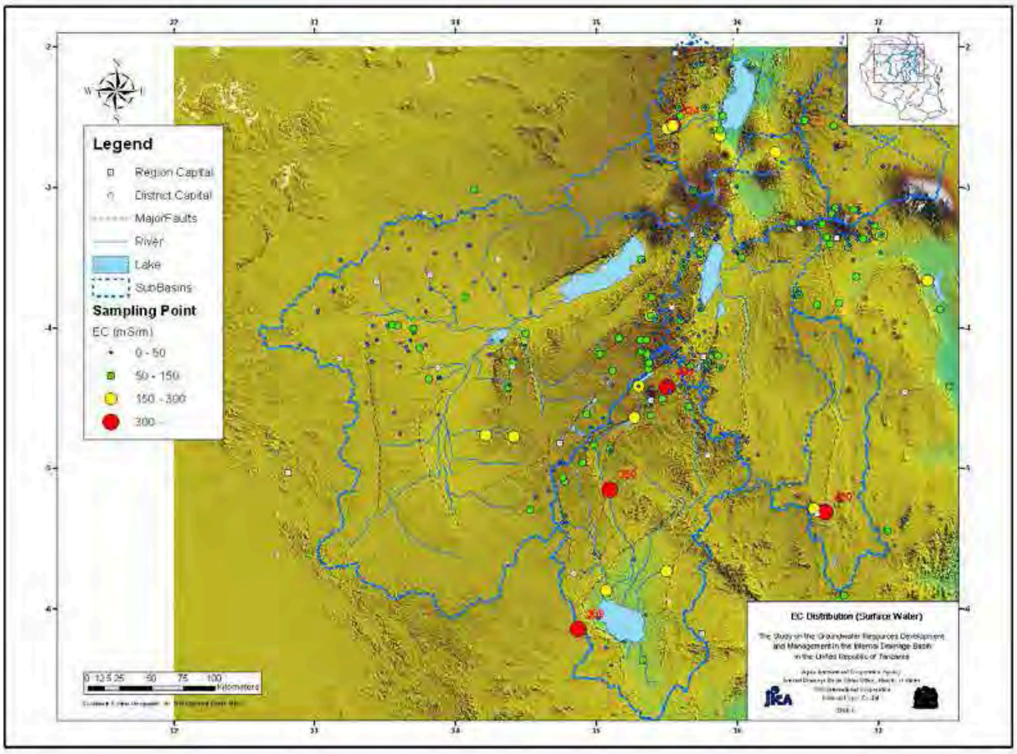


Figure 7-7 Distribution of EC in the Surface Water in IDB

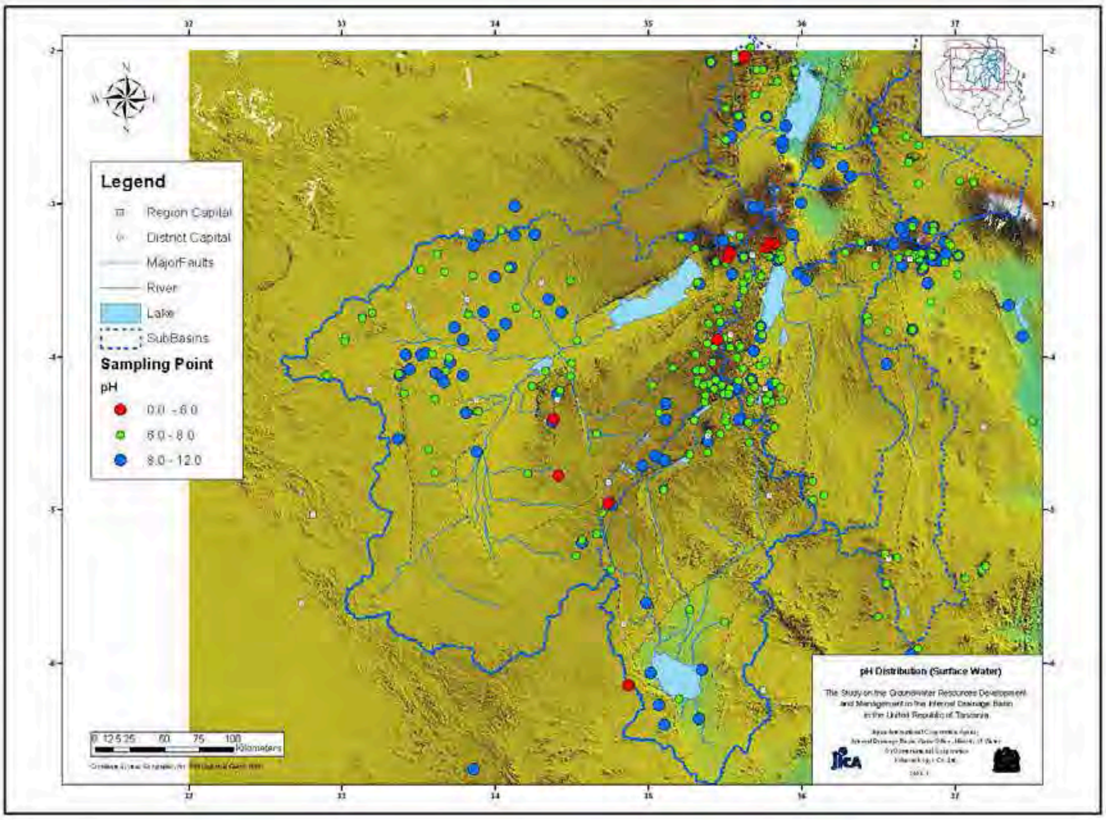
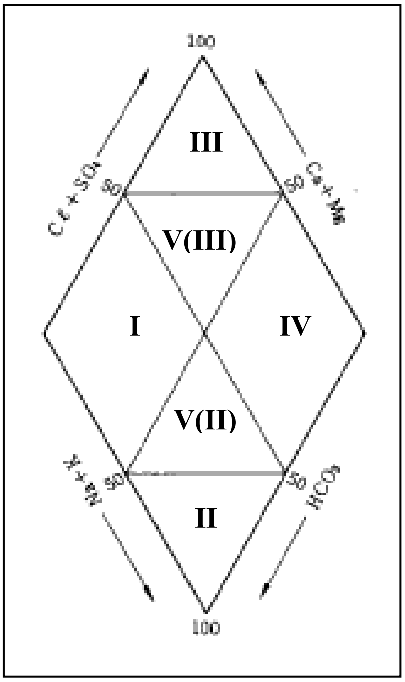


Figure 7-8 Distribution of pH in the Surface Water in IDB

Trilinear diagrams of the major components (Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-} SO_4^{2-} and HCO_3^{-}) in the surface water were drawn on the basis of analysis results of water at each source obtained from the laboratory test in this study. Figure 7-9 shows the trilinear diagrams for the river, dams and ponds and for the springs. Trilinear diagrams aim to elucidate quantitative relationships among the major components using equivalent per mole percentage (epm%) and making the classification of water quality type of water sources clear. In particular, the basis of the water quality classification is in a diamond-shaped coordinate diagram (called a key diagram). In general, water quality is classified into five types. A sample belonging to each type is considered to have the following composition.



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 confined groundwater free of saline intrusion, as retention continues, it is likely that the level of SO42- decreases through reductive reaction, where in its place HCO3- levels increase and there is more Na+ than Ca2+ due to base-exchange reaction. This transition corresponds to the transition from Type V (III) through Type I to Type V (II).

The trilinear diagrams of the surface water in this study show that the samples from the rivers, dams and ponds with low fluoride levels belong to Type I, while those with high levels belong to Type IV. For samples from the spring, those with low fluoride levels belonged to Type I as is the case with the samples from rivers, dams and lakes (above), however, those with higher levels belonged to Type II or IV. This observation indicates that there are more Type II samples from the spring than the from the river, dams and ponds and suggests that the water from the spring has longer retention time and, thus, has been exposed to chemical reactions which increase the fluoride level (e.g. elution from strata and exchange reaction) for a longer time.

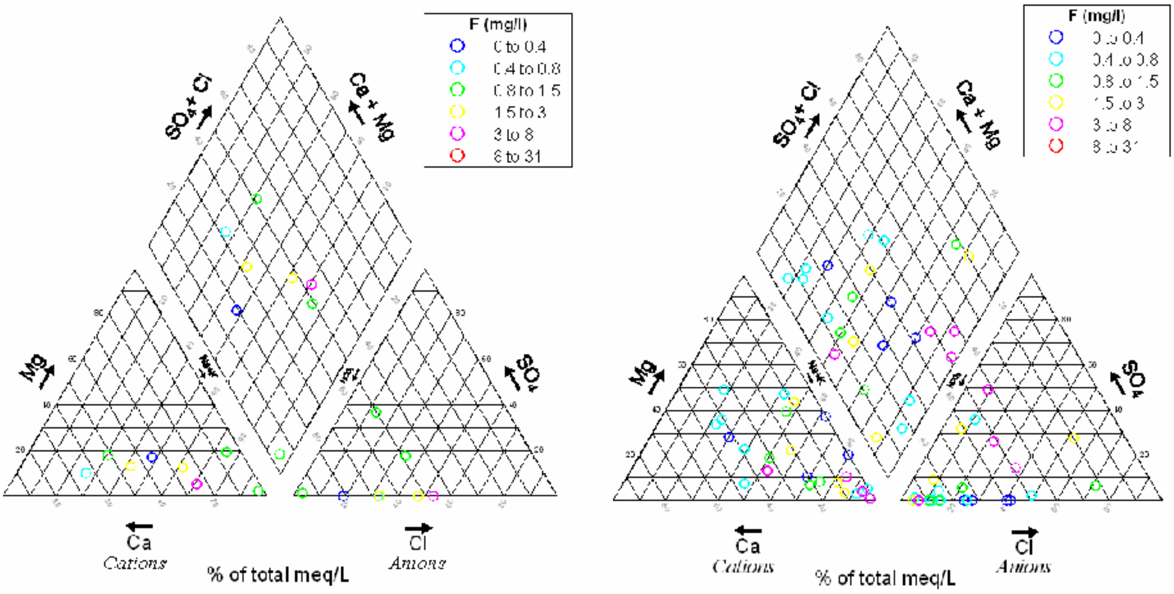


Figure 7-9 Trilinear Diagram of Surface Water in IDB

(Left figure: Dam, Pond and River; Right figure: Spring)

7.3.2 Water Quality of Groundwater

(1) Water Quality of Shallow Groundwater

Water quality of shallow groundwater (in dug wells, shallow wells and water holes) was surveyed at 868, 882 and 258 points for fluoride level, EC and pH, respectively, along with available data, the simplified water quality test and the inventory survey. Table 7-12 shows the averages and frequencies of occurrence of fluoride levels (F), electric conductivity (EC) and pH of the surface water. Figures 7-10, 7-11 and 7-12 show the distribution patterns of fluoride levels, electric conductivity and pH, respectively, of the shallow groundwater in the study area.

The highest fluoride level among the six regions where this survey was conducted was observed in Arusha Region (average: 3.0mg/l), followed by Singida Region (average: 2.0mg/l). At the local level, a dug well in Esilalei Village, Monduli District, Arusha Region, had the highest fluoride level of 25mg/l. Water in 18 percent of the samples exceeded the water quality standard for fluoride in drinking water in Tanzania (fluoride level of 4mg/l or less).

Among the six regions, Shinyanga Region had the highest EC (average: 98.7mS/m) followed by Dodoma Region (average: 96.4 mS/m). Seventeen percent of the samples exceeded EC of 150 mS/m.

Among the six regions, Singida Region had the highest pH (average 7.8). Five percent and four percent of the samples had pH 6 or less and pH 9.0 or higher, respectively.

Table 7-12 Concentrations and Frequency of Occurrence for Fluoride(F), 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

Fluoride (mg/l)	Dug well, Shallow well and Waterhole	
	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 (mS/m)	Dug well, Shallow well and Waterhole	
	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	Dug well, Shallow well and Waterhole	
	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

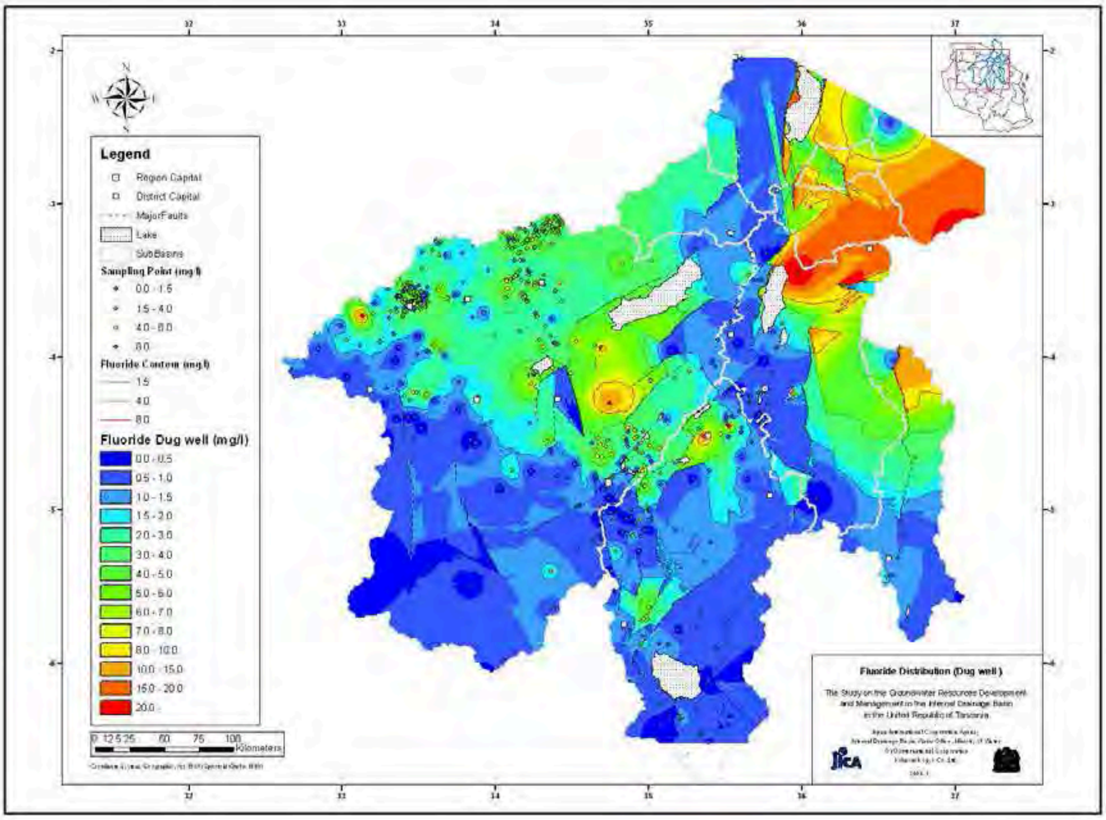


Figure 7-10 Distribution of Fluoride Concentration in Shallow Groundwater in IDB

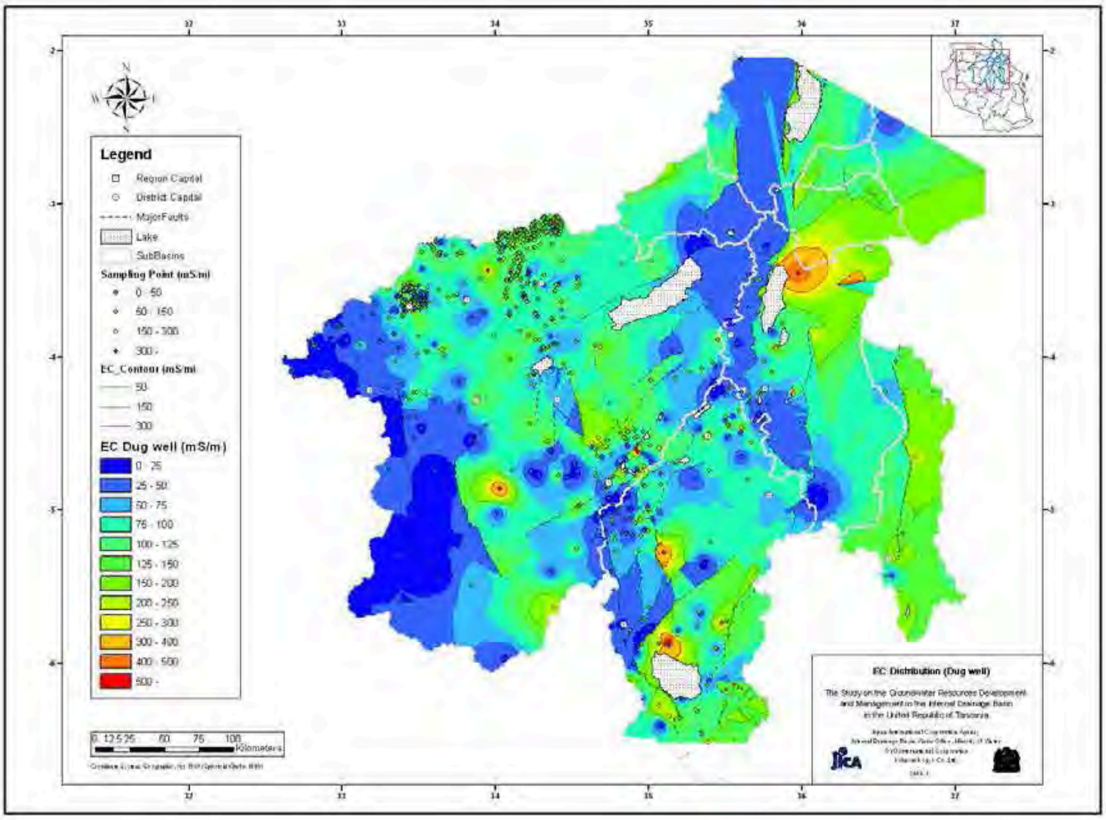


Figure 7-11 Distribution of EC in Shallow Groundwater in IDB

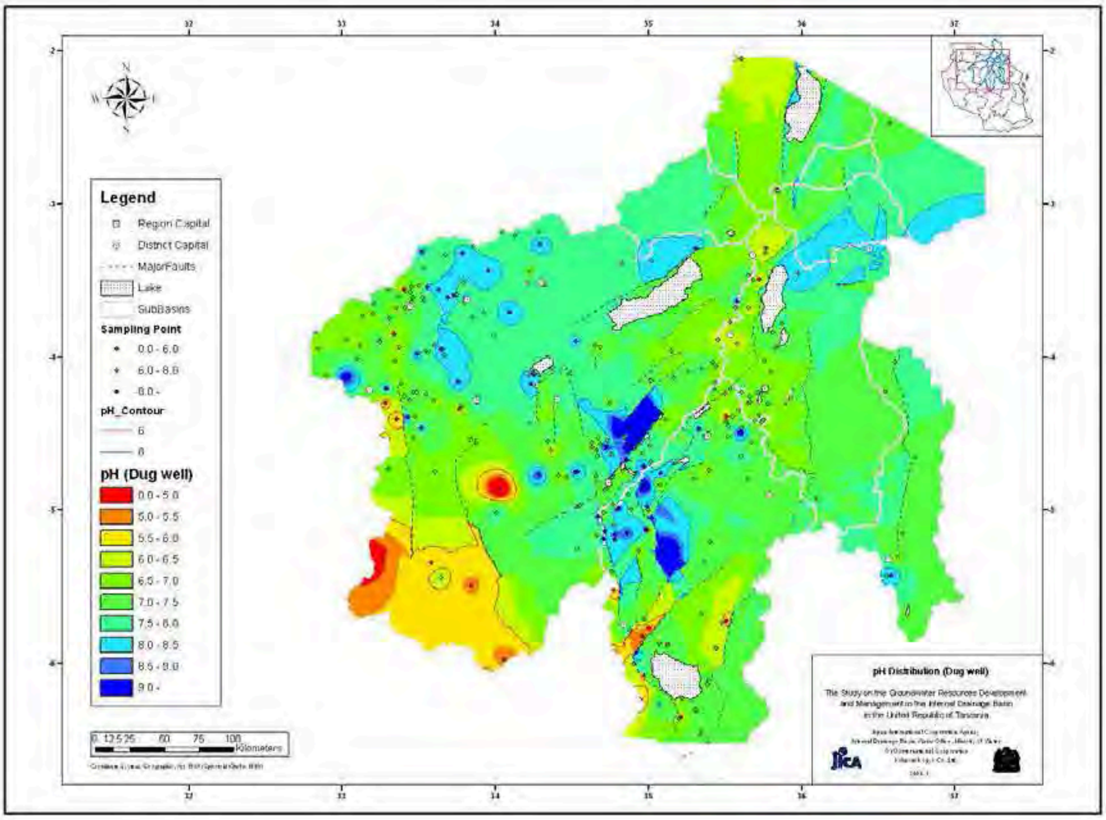


Figure 7-12 Distribution of pH in Shallow Groundwater in IDB

Figure 7-13 shows the trilinear diagram for shallow groundwater. This trilinear diagram reveals that almost all the samples of the shallow groundwater in the study area belonged to Types II, IV and V(II), where V(II) indicates an intermediate composition between Types II and IV. More specifically, the sample with low fluoride levels belong to Type IV and those with higher levels belong to Type II. These facts imply that shallow groundwater with a high level of fluoride has been retained for a longer time and exposed to chemical reactions (elution from strata and exchange reaction) which increase the fluoride levels, for a longer time, as is the case with the springs mentioned above.

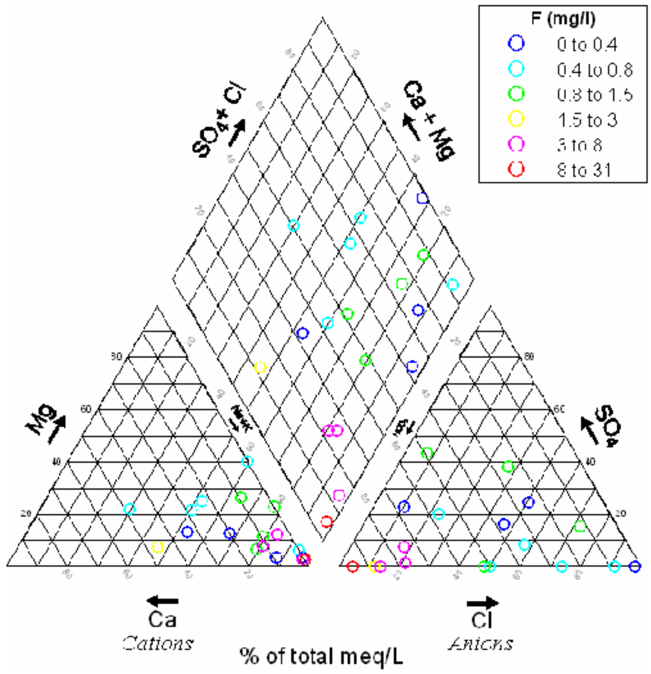


Figure 7-13 Trilinear Diagram of Shallow Groundwater in IDB

(2) Water Quality of Deep Groundwater

Water quality of deep groundwater (in borehole wells) in the study area was surveyed at 386, 413 and 382 points for fluoride levels, EC and pH, respectively, along with available data, the simplified water quality test and the inventory survey. Table 7-13 shows the averages and frequencies of occurrence of fluoride levels (F), electric conductivity (EC) and pH of the deep groundwater. Figures 7-14, 7-15 and 7-16 show the distribution patterns of fluoride levels, electric conductivity and pH, respectively, of the deep groundwater.

Among the six regions where this survey was conducted, the highest fluoride level was observed in Shinyanga Region (average: 4.1mg/l), followed by Arusha Region (average: 2.7mg/l). At the local level, the water in a borehole well in Ngofila Village, Kishapu District, Shinyanga Region, had the highest level of 35mg/l, followed by that in Piyaya Village, Ngorongoro District, Arusha Region, with 31.8mg/l. Water in 13 percent of the borehole wells surveyed exceeded the water quality standard for fluoride in drinking water in Tanzania.

Among the six regions, Shinyanga Region had the highest EC (average: 166.8 mS/m), followed by Singida Region (average: 134.9 mS/m). Thirty percent of the samples exceeded EC of 150 mS/m.

Among the six regions, Singida and Dodoma Regions had the highest pH (average: 7.5). Five percent and four percent of the samples had pH 6 or less and pH 9.0 or above, respectively.

Table 7-13 Concentrations and Frequency of Occurrence for Fluoride(F), EC and pH in Deep Groundwater in IDB

Fluoride

Region	Borehole			
	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

Unit: mg/l

Fluoride (mg/l)	Borehole	
	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	Borehole			
	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

Unit: mS/m

EC (mS/m)	Borehole	
	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	Borehole			
	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

pH	Borehole	
	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

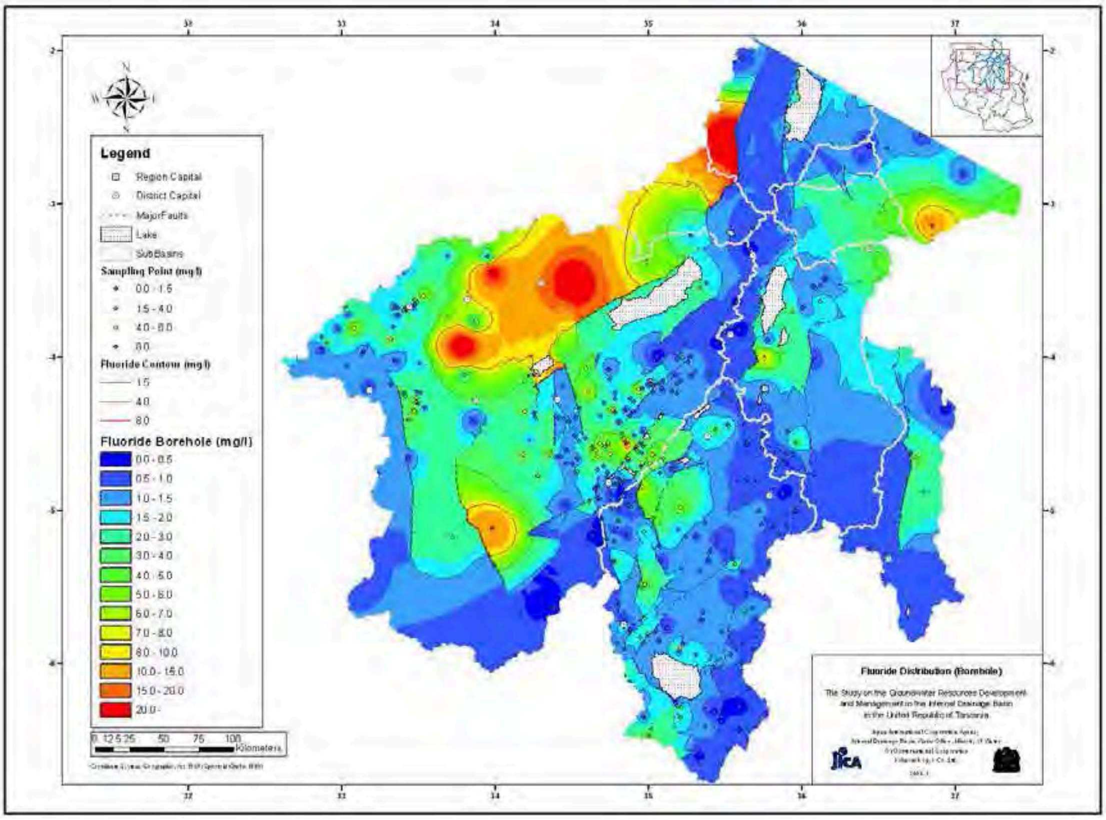


Figure 7-14 Distribution of Fluoride Concentration in Deep Groundwater in IDB

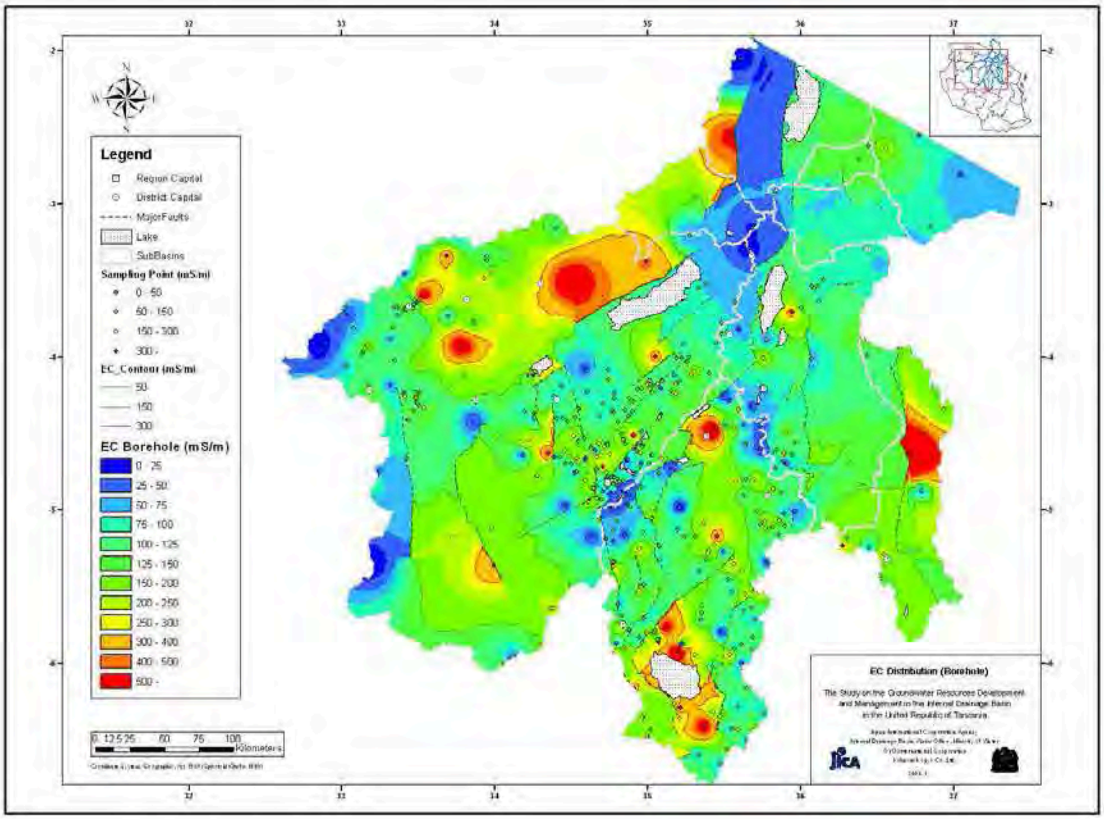


Figure 7-15 Distribution of EC in Deep Groundwater in IDB

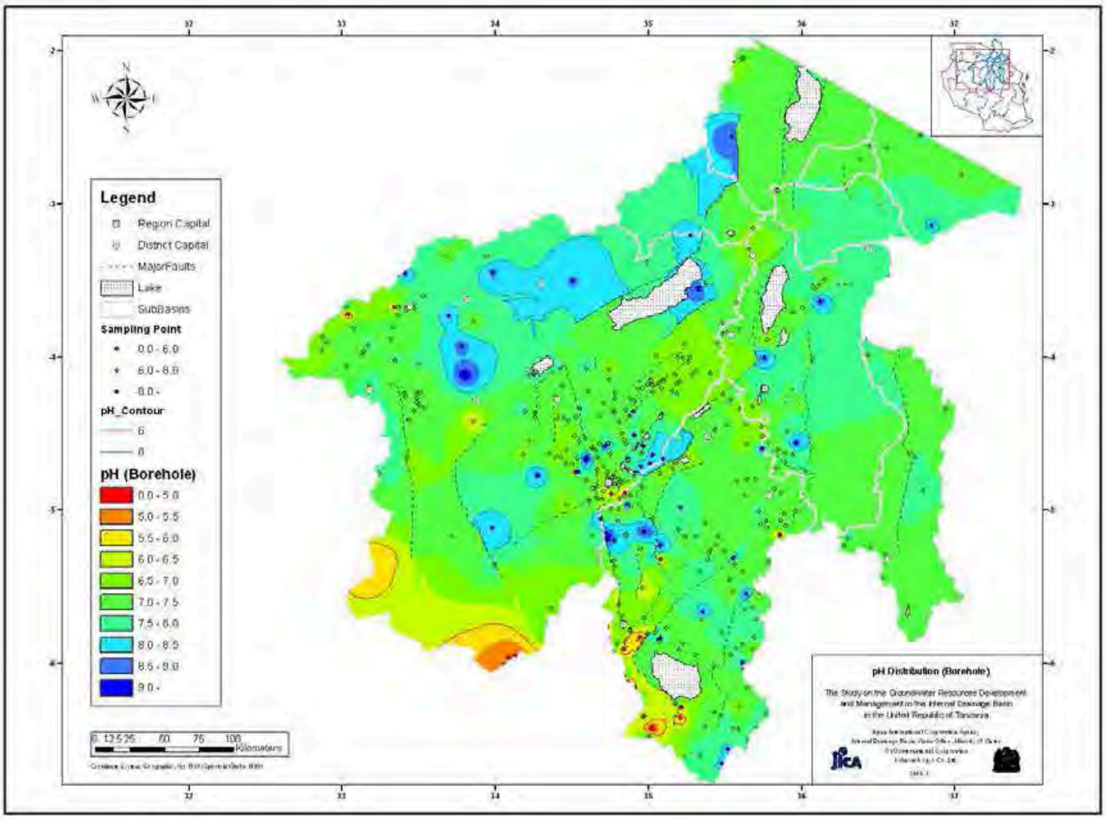


Figure 7-16 Distribution of pH in Deep Groundwater in IDB

Figure 7-17 shows the trilinear diagram for the deep ground water samples. This diagram reveals that the deep groundwater samples in this study belong to all Types, I to V. More specifically, many of the samples with higher fluoride levels belong to Types II and IV, as observed in the spring samples. The fact that the various water quality types have been observed among the deep groundwater samples in this study suggests the existence of a complicated groundwater system. As is the case with water from the springs and the shallow groundwater, the deep groundwater with high fluoride levels which belongs to Type II (alkaline bicarbonate) is considered to have had longer retention time and to have been subjected to chemical reactions (elution from strata, exchange reactions, etc.) which increases fluoride levels for a longer time. Meanwhile, the mechanism that increased fluoride levels in Type IV (alkaline non-carbonate – NaCl) deep groundwater with high fluoride levels is unknown. However, influence of fluoride derived from fluoride-rich water in many alkaline lakes in the study area is suggested as a possible mechanism.

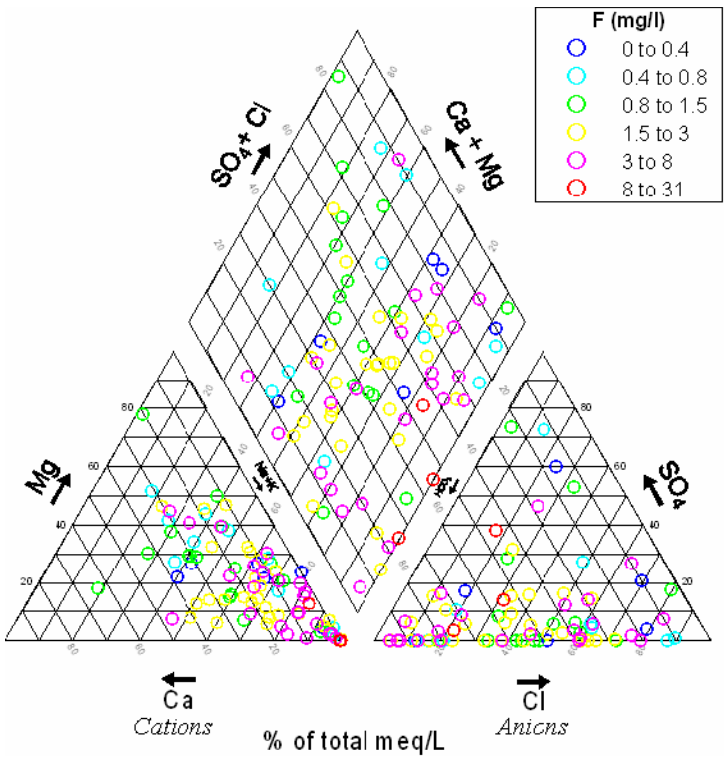


Figure 7-17 Trilinear Diagram of Deep Groundwater in IDB

7.3.3 Seasonal Changes in Water Quality at Water Sources

In the study area, significant changes in groundwater levels and distribution of quality of the groundwater are expected as precipitation in the dry and rainy seasons differ significantly. To elucidate the seasonal changes in water quality at each water source, seasonal difference in water quality was surveyed at identical points using the results of the simplified water quality test and the inventory survey. At 324 points, the water quality survey was conducted in both the dry and rainy seasons. Table 7-14 shows the provincial averages of fluoride levels (F) and electric conductivity (EC) in the rainy and dry seasons.

The fluoride level in the dry season was 1.4 times higher than that in the rainy season on average of all the samples. The difference is largest in Shinyanga Region where the level was 4.1 times higher in the dry season than in rainy season, followed by Singida Region where the fluoride level in the dry season was 2.8 times higher than in the rainy season.

In contrast to the increase observed in fluoride level, there was no significant increase observed in EC in the dry season. EC at the water sources in the dry season was 1.1 times that of the rainy season on average for all samples.

One of the possible causes of this difference is that slightly different methods of measuring fluoride levels were used in the dry and rainy seasons. With the exception of Arusha Region, all the regions used the Pack Test for the measurement of fluoride levels at water sources in the rainy season, and portable fluoride meters in the dry season. In Arusha Region, however, the portable fluoride meters were used in both the rainy and dry seasons in most cases. It is difficult to measure high level fluoride (1.5mg/l or above) with the Pack Test for fluoride, and thus fluoride levels may have been underrated in the survey in the rainy season in Shinyanga and Singida Regions, which have many water sources with high fluoride levels. No significant difference was observed between the rainy and dry seasons in fluoride levels at all water sources in Arusha Region, where portable fluoride meters were used to conduct the survey in both seasons.

These facts suggest that the seasonal change in fluoride levels at each water source in the study area is similar to that in electric conductivity, and that the level increases slightly in the dry season.

Table 7-14 Average of F and pH in Water Sources in Rainy and Dry Seasons

F

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**

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

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

7.3.4 Water Pollution at Water Sources

It is believed that water in many areas of Tanzania contain substances pertaining to water quality other than fluoride, such as nitrate, iron and coliform bacteria, with the levels that exceed the Tanzanian standards and/or the WHO guideline values. However, the status of such water pollution is not fully understood. In order to clarify actual water pollution at water sources in the study area, the quality of water sources was studied using the simplified water quality test and detailed laboratory test.

(1) Nitrate, Ammonium, Iron, Manganese and Coliform Bacteria at Water Sources

Table 7-15 shows the frequencies of occurrence and levels of nitrate, ammonia, iron, manganese and coliform bacteria at each water source in the study area.

It is generally considered that contamination from human and livestock excreta is the cause of increased nitrate levels. A high nitrate level of 40mg/l or above was observed most frequently among the dug wells (12 to 13 percent of the 104 points in both the rainy and dry seasons), followed by the boreholes (seven to eight percent of the 88 points).

Similar to nitrate, it is considered that contamination from human and livestock excreta also causes an increase in ammonium levels. A high ammonium level of 2mg/l (the Tanzanian standard for drinking water) or above was found most frequently among the rivers, dams and ponds (8 to 16 percent), followed by the dug wells (seven to eight percent).

A high iron level of 1mg/l (the Tanzanian standard for drinking water) or above was found most frequently among the dug wells (two to eight percent). It was also observed in two to five percent of other water sources.

A high manganese level of 0.5mg/l (the Tanzanian standard for drinking water) or above was found most frequently among the boreholes (13 to 22 percent) and the rivers, dams and ponds (16 to 21 percent).

Twenty-two to 52 percent of all the water sources other than boreholes were contaminated excessively with coliform bacteria, while seven to 15 percent of the boreholes were also contaminated excessively with the bacteria.

Table 7-15 Frequency of Occurrence for NO3, NH4, Fe, Mn and Coliform Bacteria in Water Sources in IDB

Region	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 7-18 shows distribution of the levels of nitrate, ammonium, iron and manganese at water sources in the study area in the dry season.

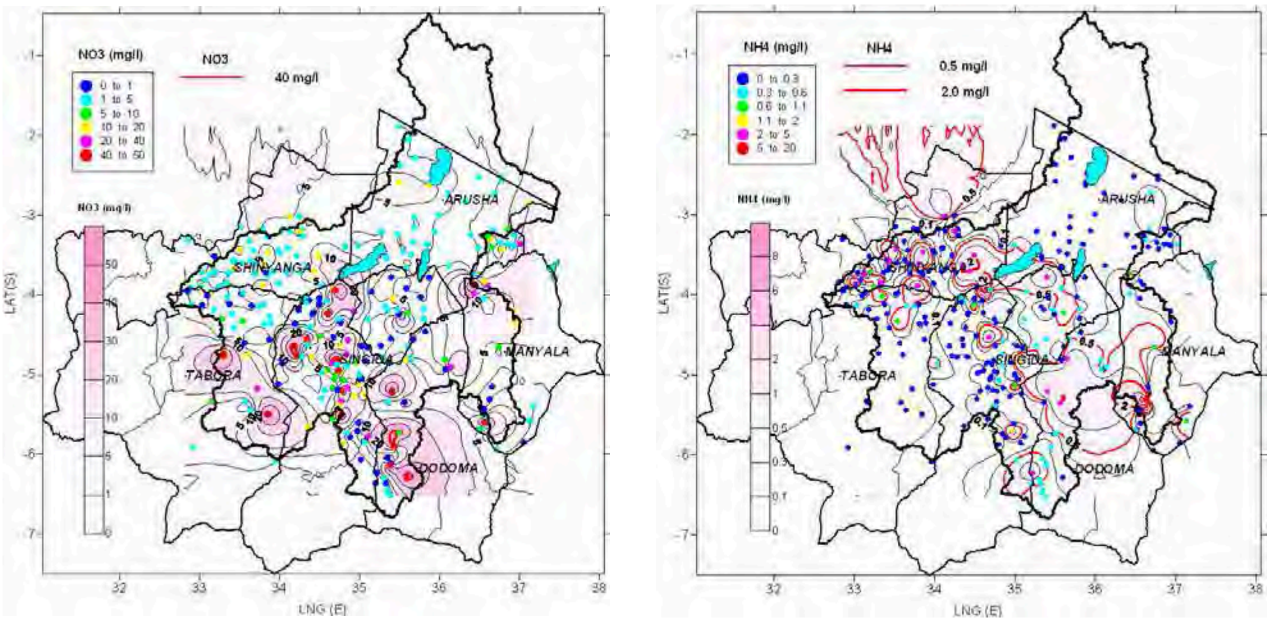


Figure 7-18 Distribution of NO_3 and NH_4 in Dry Season in IDB

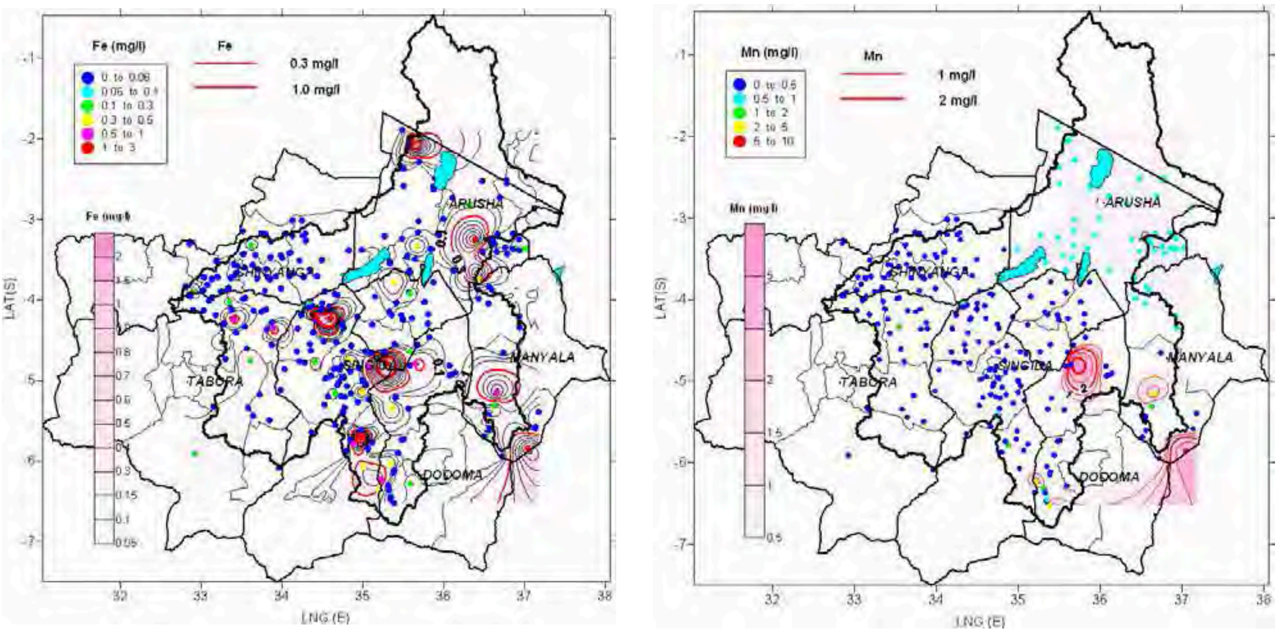


Figure 7-19 Distribution of Fe and Mn in Dry Season in IDB

(2) Hazardous Materials at the Water Sources

The analysis results from the laboratory test of water quality were used to confirm compliance with each of the standards of water at the existing water sources in the study area for chemical hazards of health concern (hazardous materials) and drinking and household water quality provided by the Tanzanian Authorities and by the WHO guidelines. Figure 7-20 shows the compliance of the sample taken from the existing water sources for the laboratory test conducted in this study.

Among heavy metals in the chemical hazards of health concern, hexavalent chromium and barium exceeded the Tanzanian and WHO standards in one and six (4.3%) samples, respectively, out of a total 139 samples. Among the standards for drinking and household water quality, color, turbulence and pH exceeded Tanzanian standards in 12 (8.6%), nine (6.5%) and ten (7.2) samples, respectively. On the other hand, in the case of the WHO standards, the same parameters for color, turbidity and pH exceeded standards in 15 (10.8%), 20 (14.4%) and 28 (20.1%) samples, respectively. While no sample exceeded the Tanzanian standard for zinc, three (2.2%) exceeded the WHO standard (guideline value). Biochemical oxygen demand (BOD) and Potassium Permanganate ($KMnO_4$), the indicators of organic matters in water, exceeded the Tanzanian standards in 22 (16.1%) and 33 (23.7%) samples, respectively.

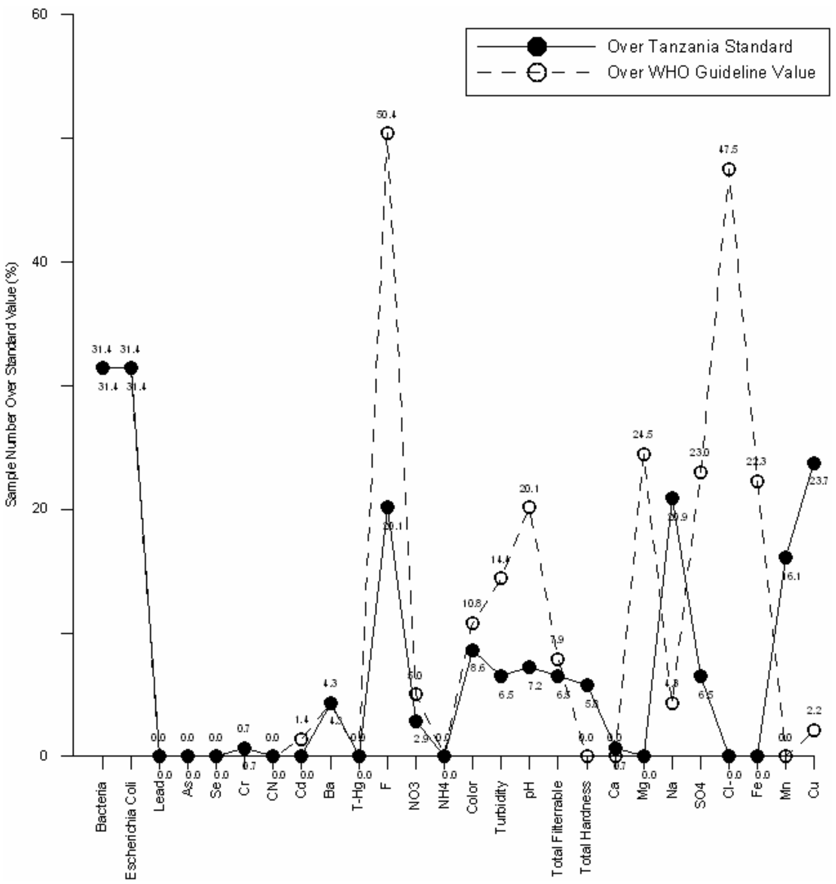


Figure 7-20 Compliance to the standards for drinking water

7.3.5 Sources of High Fluoride Content in Water Sources Based on Existing Materials

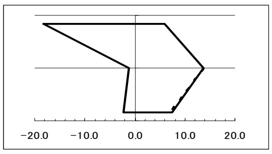
The occurrence of fluoride generally depends on the type and composition of bedrock, the existence of hydrothermalism, atmospheric deposition and anthropogenic sources. It is said that there are about 150 fluoride bearing minerals, however villiaumite, fluorospars, flourapatile and cryolite are the most abundant ones. Many rocks of the Rift Valley are enriched in those minerals. This especially concerns amorphous rocks, like pumice, tuffs, pyroclastics and porphyry or other easily weathered materials, like volcanic ash or sediments of alkaline salt lakes, by washing out the fluorine component into the surface water and groundwater. Leaching out the fluoride from easily weathered volcanic rocks and infiltration of fluoride from the alkaline lakes (or sediments of alkaline salt lakes) to the groundwater are thought to be the main sources of high fluoride levels in water sources in the study area. The input of fluoride into the water sources caused by atmospheric deposition or anthropogenic influences can be ignored. (Mwende, E., 2000)

7.3.6 Relationship between Fluoride and Other Water Quality Parameters at Water Sources

The relationship between fluoride and other water quality parameters based on the laboratory test data was checked. When all the deep groundwater samples from the entire basin were analyzed, little significant correlation was detected between fluoride and the other water quality parameters. However, when the correlation was analyzed at the sub-basin level, relatively strong correlation was detected with barium (Ba), pH, hardness, calcium (Ca), magnesium (Mg), sodium (Na), bicarbonate (HCO_3^-), chloride (Cl^-), boron (B) and electric conductivity (EC) compared with the other parameters. Figure 7-20 shows the relationship between fluoride and other water quality parameters in the deep ground water (borehole wells) in sub-basin A. From an overall standpoint, pH, Na, HCO_3^-, B, Cl^- and EC show a positive correlation versus fluoride. On other hand, Ba, hardness, Ca and Mg show a negative correlation. In particular, the enrichment of F^- in the deep groundwater is closely related to the decrease of Ca and Mg and increase of Na, HCO_3^- and Cl^-.

The correlation detected at the water sources in the study area suggests that some of the fluoride-rich water sources belong to Type II (alkaline bicarbonate) and others belong to Type IV (alkaline non-carbonate / NaCl) in the trilinear diagram as mentioned in 3.2.2. With the aim to elucidate supply sources of fluoride to the 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 levels of these components and a narrow diagram indicates low levels.

Figure 7-21 shows the hexa diagram for all the samples in the study area. Figure 7-22 shows the hexa diagram for sub-basin A, which has a relatively large number of fluoride-rich water sources. The points with high fluoride levels 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 geological structure with high fluoride levels which are dotted with alkaline (NaCl) lakes with high fluoride levels.



A hexa diagram, like the one shown in the figure on the right, was obtained at many of the water sources with a fluoride level of 8mg/l or above. The shape of this diagram indicates that high levels of Na^+ and K^+ and low levels of Ca^{2+} among the cations, and high levels of HCO_3^- and low levels of Cl^- among the anions.

In addition to the previous diagram, a diagram of a wide reverse-triangular shape was obtained at a significant number of the water sources with a fluoride level of less than 8mg/l. The shape of this diagram indicates that the levels of Na^+ and Cl^- are the highest among the cations and the anions, respectively. In the southern part of the study area, some water sources resulted in one of the two types of hexa diagrams. However, the relatively low level of fluoride at these water sources suggests that there are few fluoride supply sources which have high fluoride levels like those mentioned above in this section.

The analysis results with hexa diagrams and the above-mentioned trilinear diagrams have revealed that some of the fluoride-rich water sources in the study area have high levels of alkaline bicarbonate ($NaHCO_3$) and others are rich in alkaline non-carbonate (NaCl). In addition, the water sources characterized by alkaline bicarbonate ($NaHCO_3$) tend to have higher fluoride levels than those of alkaline non-carbonate (NaCl). A mechanism reported by Gunnar Jacks and others (2005) that increased fluoride levels in the alkaline bicarbonate ($NaHCO_3$) type groundwater explains that the high fluoride level of groundwater in South India is closely related to a decrease of Ca and Mg and increase of Na and HCO_3^-. Calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) such as carbonate minerals release HCO_3^- by weathering. From the relationship of these water quality parameters (Ca, Mg, Na and HCO_3^-) and F^-, the enrichment of F^- in the groundwater is considered to take place through the weathering of minerals with high fluoride and the precipitation of carbonate minerals by evapotranspiration as shown in Figure 7-23.

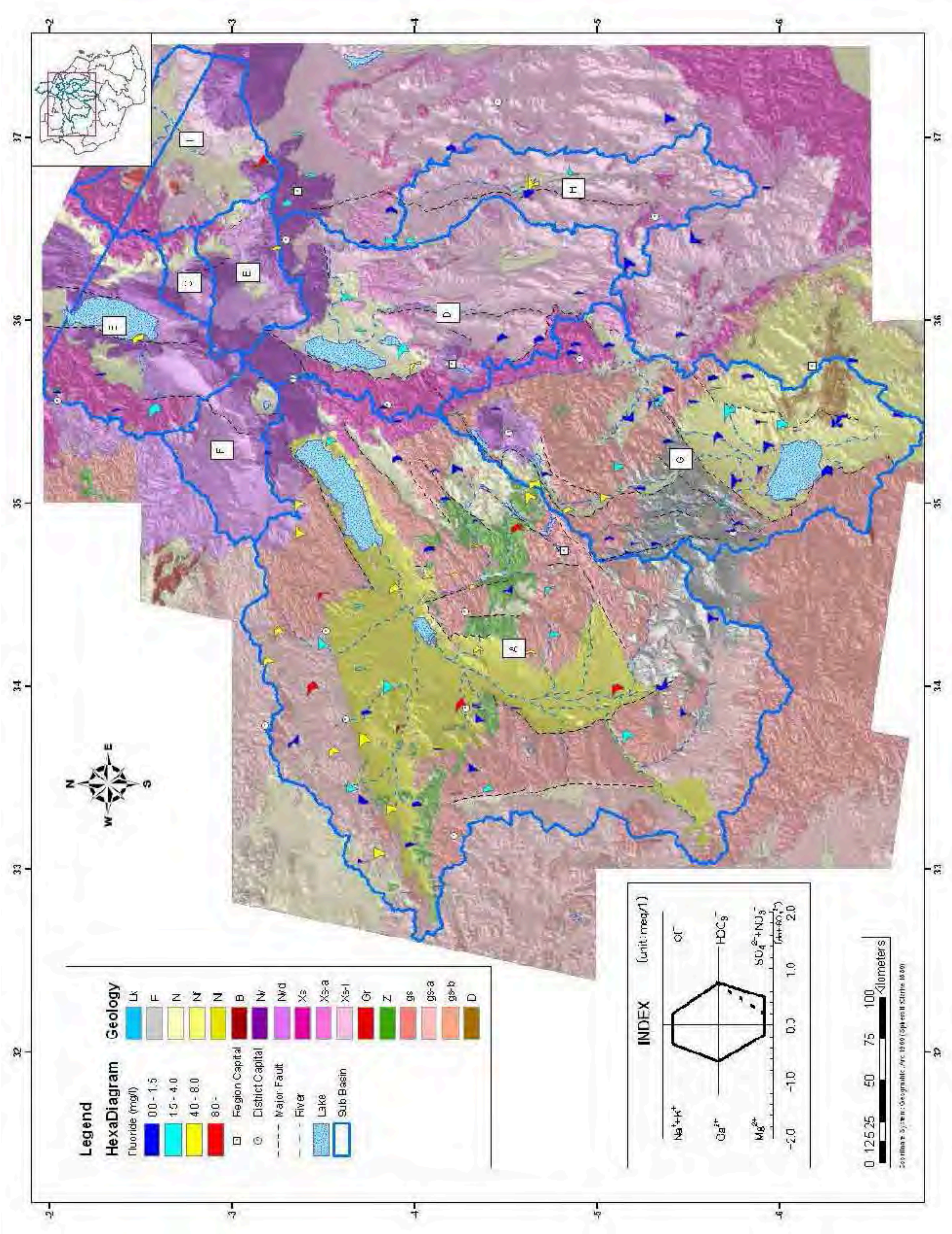


Figure 7-21 Hexa Diagram in Existing Water Sources in the Whole Basin

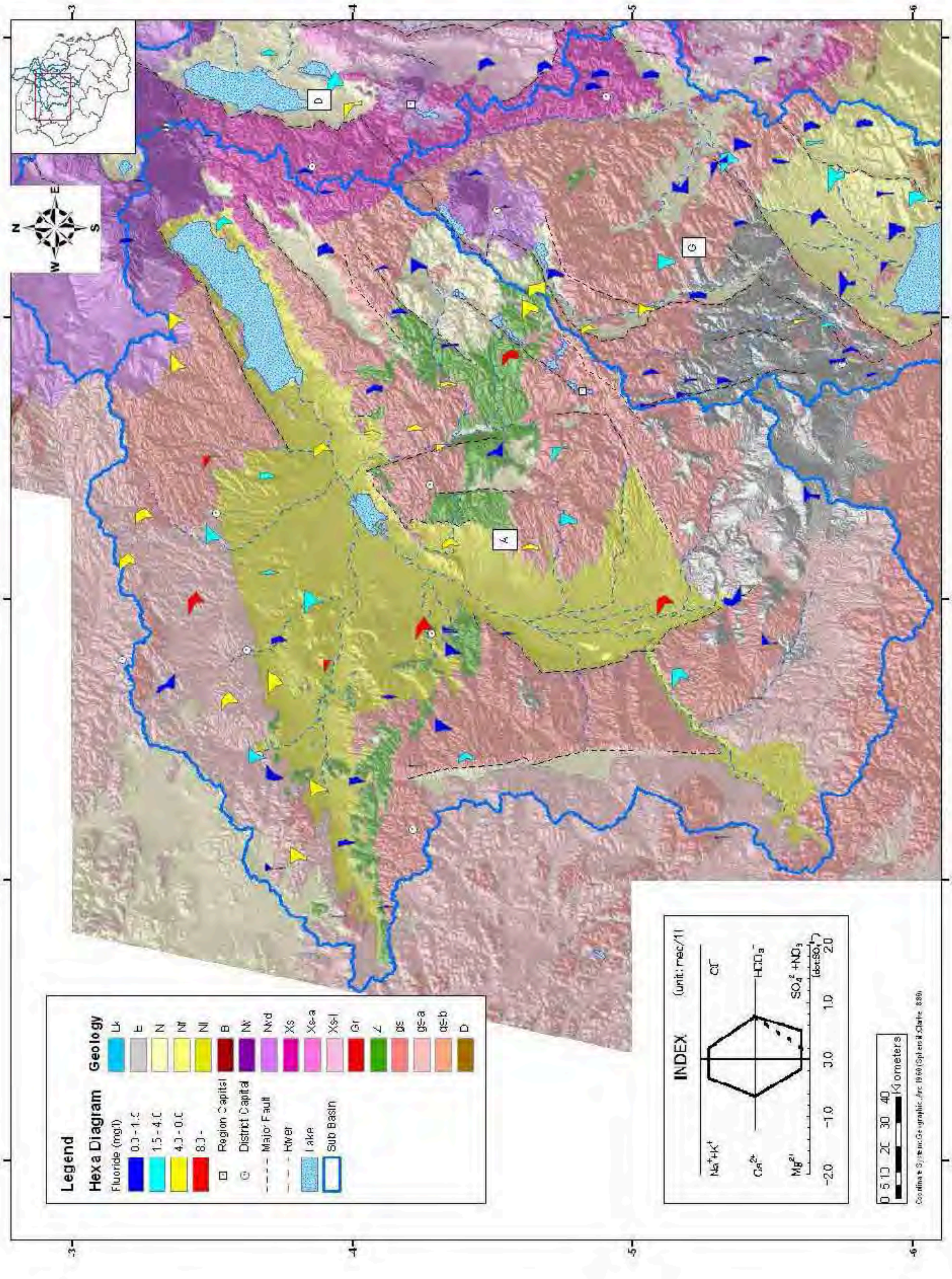


Figure 7-22 Hexa Diagram in Existing Water Sources in Sub Basin A

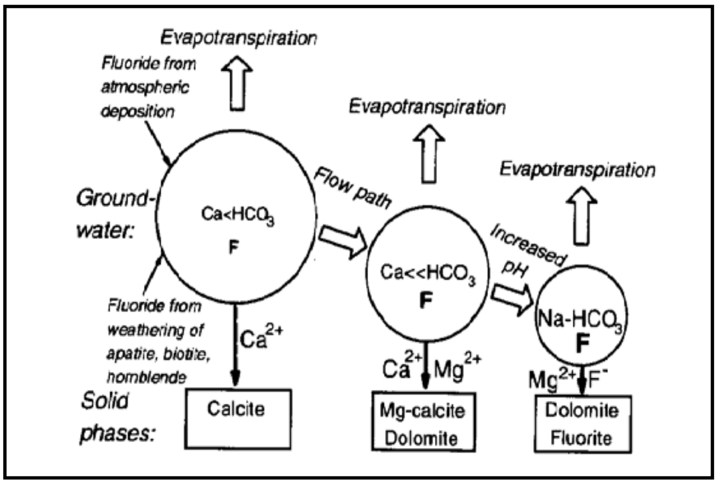


Figure 7-23 Mechanism of Formation of High-F-Groundwater in South India

(Source: Gunnar Jacks et al., "Controls on the Genesis of Some High-Fluoride Groundwater in India," 2005)

From the above-mentioned results, the effect (infiltration) of fluoride from the alkaline lakes to the groundwater, as well as elution from the volcanic strata, is considered a possible supply source of fluoride to the water sources in the study area. Groundwater is more likely to be affected by elution of fluoride from strata in the area in which it is retained for a longer time. In addition to the elution, evapotranspiration and exchange reaction with carbonated minerals are considered as possible causes of extremely high fluoride levels in the groundwater in the study area.

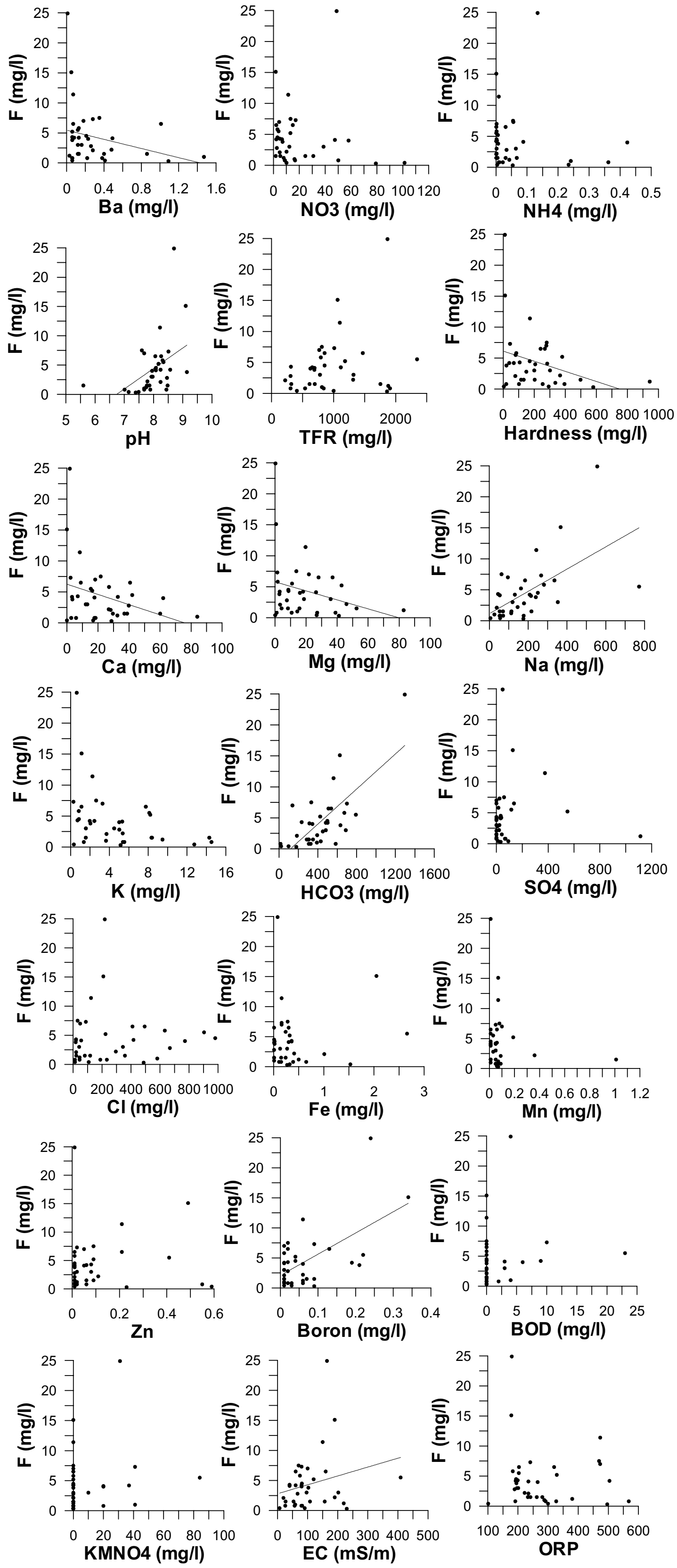


Figure 7-24 Relationship between Fluoride and Other Water Quality Items in Deep Groundwater (Borehole Wells) in Sub-basin A

Chapter 8
Fluoride Problems and Water Related Diseases

CHAPTER 8 FLUORIDE PROBLEMS AND WATER-RELATED DISEASES

8.1 Fluoride Diseases Problems and Removal Measures

8.1.1 Health Effects of Fluoride

Fluoride is a nutritionally important mineral found in the enamel of the teeth, bones and in minute quantities in other body tissues. Approximately 99% of the fluoride in human is present in the bones and teeth. WHO standard for optimum levels of fluoride consumption of drinking water is 1.0 - 1.5 mg/L. In Tanzania a temporary standard for drinking water accepts a fluoride concentration of 8 mg/L. A number of water sources in many places exceed the Tanzania temporary standard of fluoride. For instance the highest fluoride ingestion in drinking water in Arusha district had been observed at Oldonyowas village, where two water sources had fluoride content of 14 mg/L and 19 mg/L, respectively (Mjengera, 1988).

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 are harmful and cause fluorosis as shown in Table 8-1. 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).

Table 8-1 Categories of Fluorosis

Drinking water Conc. (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.

Another factor thought to be contributing to the increase in human exposure to fluoride and consequently fluorosis, is the fluoride content in food, which is attributed to the following factors (WHO, 1970):

Use of water containing excess fluoride concentration in food processing;

Exposure of crops to airborne fluoride (gaseous industrial waste, burning of coal and gases emitted from volcanic areas increase the amount fluorides in the air), and waterborne fluoride in areas irrigated with water containing high fluoride concentration; and use of fluoride containing fertilizer.

In Arusha, Arumeru, Singida and Iramba areas, high concentrations are ingested from foodstuffs. In preparing food, a locally obtained salt called 'Magadi' also known as "Trona", is added to the food in order to speed up the cooking process. The 'Magadi' salt occurs as a whitish encrustation in dried up basins and on the riverbanks in the dry seasons. Trona (sodium carbonate) has been found to be highly contaminated with fluoride. The compound may contain 20 – 14,960 mg/L fluoride. Samples of Magadi collected from Sepuka and Kinyeto areas in Singida contained fluoride in the range of 36 - 180 mg/L and 28 – 900 mg/L, respectively. In Iramba the fluoride content in Magadi samples ranged from 690 – 6,800 mg/L (Mabelya, 1994). It was also observed that urine samples from infants in Iramba had twice as high fluoride levels than urine samples from Singida (Mabelya, 1994).

Additional fluoride concentrations to the body can result from fluoride tablets, fluoride ingredients in toothpastes, table salt, insecticides, etc. Factors governing the harmful effects from fluoride ingestion include:

Age - Children are more affected than adults because in children the fluoride has readily available sites in which it can enter i.e., teeth and bones that are forming.
Nutritional status - Inadequate intake of nutrients such as proteins, calcium and vitamin D enhance the severity of fluoride toxicity.
Type of minerals present in water - The harmful effects of fluoride on bones and teeth are more pronounced and severe in individuals who drink water of low hardness. Low calcium and magnesium contents and high alkalinity increase the risk of fluorosis (Nanyaro et al., 1984).

Body size - Fluoride is said to be a bone-seeking element. The amount of total fluoride that would be toxic for a person with a small stature and consequently small skeleton may be expected to be less toxic than that for a person with a big stature with relatively big skeleton. (Srikantia 1974 in Kaseva, 1992).
Sex - Men are more affected than women for reasons not fully understood (Aswathanarayana et al 1974 in Kaseva, 1992).

(1) Dental Fluorosis

Dental fluorosis is caused by excessive deposition of fluoride in the enamel leading to mottling and discoloration of the teeth (Figure 8-1). The occurrence of dental fluorosis in Arusha region is observed to be very high ranging from 83% to 95% (Mjengera, 1988).

Figure 8-1 Symptoms of Dental Fluorosis (Kaseva, 2005)

In 1977 random samples of children born and brought up in areas with 3 mg/L fluoride in Arusha and 6 mg/L fluoride in Kisongo area in Arusha region, were examined.

The findings indicated a progressive increase in the severity in dental fluorosis with the increase in fluoride concentration in drinking water (Mjengera, 1988).

Findings of a study in Singida and Iramba by Mabelya (1994) indicated that the prevalences of dental fluorosis were 72.0% and 99.3%, respectively, despite low fluoride concentrations in drinking water in the areas. Thus, the prevalence of fluorosis in Singida and Iramba is probably attributed to the consumption of Magadi (Mabelya, 1994). As noted earlier, samples of Magadi from the areas contained 28 – 6,800 mg/L fluoride.

(2) Skeletal Fluorosis

Skeletal fluorosis is the gross appearance of the bones, which have been induced due to early calcification of tendons, ligaments and joint capsules all over the body especially in the vertebral (WHO, 1970). The clinical symptoms resulting from skeletal fluorosis include the following:

- ✓ Joint pains at the knees, ankles, chin, cervical, spine, hip and joints of the arm;
- ✓ Backache;
- ✓ Bow legs and knocked knees;
- ✓ Stiffness of the trunk and hampered movement of limbs.

Skeletal fluorosis has been observed in some of severely hit areas e.g., Maji ya Chai village in Arusha region (Figure 8-2), where water sources have been found to contain 20 mg/L fluoride concentration. Although Maji ya Chai village is not among the study areas of this project, findings from the area are included in this report because the fluorosis cases in Maji Chai village exemplify the health effects of fluoride in Tanzania, and lack of literature on similar studies in the study areas.

Figure 8-2 Symptoms of Skeletal Fluorosis (Kaseva, 2005)

(3) Crippling Fluorosis

Crippling fluorosis is the later stage of fluorosis that is characterized by fixed kyphosis and severe joint contractures (Figure 8-3). Kyphosis means forward bending of the spine (Teri, 1982 in Mjengera, 1988). An affected person has difficulties in walking due to partial stiffness and limitation of movement of various joints. The problem predominated in adults beyond 40 years. It is noted that the above reported cases of skeletal and crippling fluorosis in Arusha region (Figures 8-2 and 8-3) were not corroborated with clinical data that would indicate the concentration of fluoride in the body tissues of the individuals.

A resent 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 (Figure 8-4). Table 8-2 shows occurrence of fluorosis in school children in Maji ya Chai Ward in Arusha region expressed in terms of Dean Index.

Figure 8-3 Symptoms of Crippling Fluorosis (Eliuza, 2004)

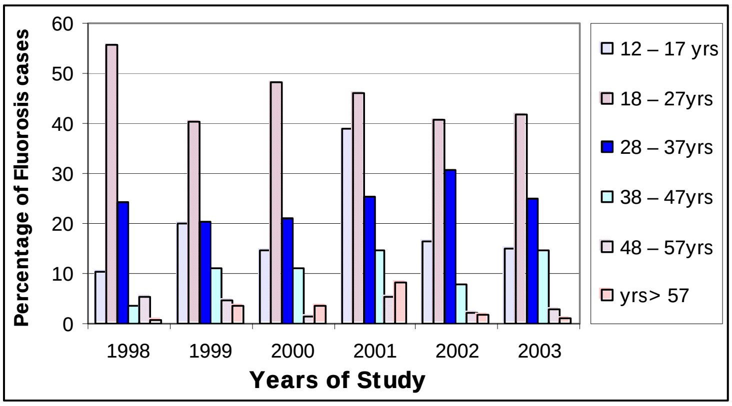


Figure 8-4 Percentage Distribution of Fluorosis Cases among Age Groups in Maji ya Chai Village, Arusha Region (Eliuza, 2004)

Table 8-2 Occurrence of Fluorosis in School Children in Maji ya Chai Ward in Arusha Region expressed in terms of Dean Index (modified from Eliuze, 2004)

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)

8.1.2 Fluoride Removal Techniques

Removal is hereby defined to refer to the total effects of all possible mechanisms that remove or reduce fluoride in treated water. The removal of fluoride in one word is defluoridation. The technology of defluoridation has been to some extent well developed and tested. 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. Fluoride removal techniques include the following.

(1) Chemical Methods

Chemical methods are of two types: The first type involves additive method in which one or more chemicals are added to the water to cause precipitation or co-precipitation during coagulation. Fluoride is absorbed and both the additive and the fluoride are consequently removed using conventional treatment processes such as sedimentation and filtration. Chemical addition includes the use of lime, magnesium salts, aluminium salts, etc. The second type involves adsorption method consisting of a bed of filter of generally insoluble material through which the water is allowed to percolate. Fluoride is removed by ion exchange or adsorption and the filter material is periodically replaced or regenerated when it becomes saturated with the fluoride removed. Adsorbents include activated alumina, activated carbon, anion exchange resins, limestone etc (Mcharo, 1986).

i) Filtration through Activated Alumina

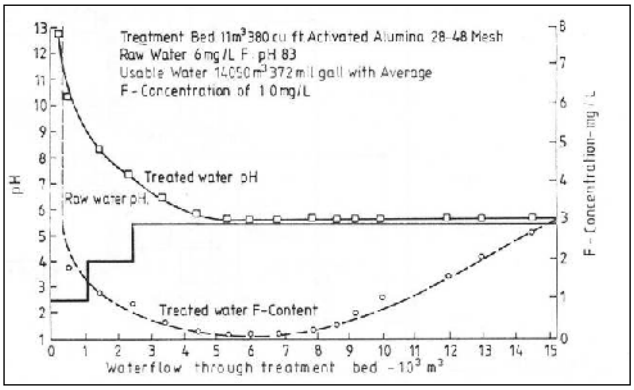


Figure 8-5 Typical Operational Run at Gilabend Arizona, USA using Activated Alumina Media

Granular activated alumina, which is mostly used in the process, is a by-product of aluminum production. It is primarily an aluminum oxide activated by exposure to high temperature. The material is very porous and gives high surface area per unit weight. This process is one of the most efficient methods for fluoride removal. Aluminum, with a positive three-valent charge, strongly attracts the electronegative fluoride ion. The aluminum process requires pH adjustment of raw water to 5.5 for maximum fluoride removal (Figure 8-5). After treatment the pH can be adjusted to the desired level. During the treatment fluoride ions are attracted and held to the vast surface area throughout the pores of the alumina grains and the attractive forces are strongest in the pH range of 5.0 to 6.0 (Mcharo, 1986). At the optimal pH for fluoride removal, some organic molecules and some trace heavy metal ions are adsorbed but they are completely regenerated along with the fluoride. These ions compete for the same adsorption sites with the fluoride and their presence depletes the fluoride removal capacity of the alumina (Mcharo, 1986). Arsenic presents a problem as it is preferentially adsorbed over fluoride by the alumina at the same optimum pH. Arsenic is more difficult to regenerate than fluoride and a special treatment technique is required when excess fluoride and arsenic are present in water (Rubel 1984 cited by Mcharo, 1986). The process removes about 95% of fluoride in raw water for the initial stage and as the treatment continues the activated alumina grains absorb fluoride ions until saturated. This method can reduce the fluoride concentration to 1.0 mg/L.

The process of regeneration by caustic soda releases and totally removes fluoride ions resulting to wastewater volumes of approximately 4% of the total influent. The wastewater has a high pH value. The most efficient method of regenerating a treatment bed upon completion of a treatment run includes two regeneration steps. The first step is a backwash mode, which is done after draining the bed, and it involves up-flow rinse using raw water followed by draining the unit. The second regeneration involves a down-flow through the treatment bed. In both steps a 1% by weight NaOH solution is used and it is the maximum concentration required for high efficiency regeneration. The object of regeneration is to remove all fluoride ions from the bed before any part of the bed is returned to treatment mode. Fluoride ions loose their attraction or adsorption forces and become repelled by the alumina when pH rises above 7.5. The higher the pH, the faster and more efficient the regeneration. On the other hand, maintaining high pH involves higher cost due to higher caustic consumption. Neutralization mode is important after the treatment run. The object of this mode is to return the bed to the treatment mode as rapidly as possible without dissolving the activated alumina. The pH of the treatment media after the completion of regeneration process is about 12 and it must be adjusted down to 5.5 by using concentrated sulphuric acid. Activated alumina deteriorates with time due to abrasion and irreversible exchange reactions. A life cycle of about 4 years may be assumed and about 25 % of fresh alumina may have to be added annually (Schoeman, 1984 cited by Mcharo, 1986). Apart from the high efficiency in removing fluoride from water, this is a fairly complicated process that needs skilled manpower.

ii) Treatment with Bone Char

The affinity of fluorides to bones suggests the use of some suitable form of bone media for reducing fluoride concentration in water. Bone and dental enamel is essentially calcium phosphate ($Ca_3(PO_4)_2$ $CaCO_3$) and in the presence of fluorides, the carbonates are replaced by the fluoride forming a more insoluble fluoro-apatite. This compound can be returned to a form suitable for repetitive fluoride adsorption with a caustic solution. This result into the formation of hydrox-apatite with fluoride removed as sodium fluoride (Mcharo, 1986). Several plants using bone char as the medium for fluoride removal are in operation in the USA. For example a treatment plant at Britton, South Dakota. After treating about 1800 m^3 of water the bone char becomes saturated with fluorides and has to be regenerated. Regeneration consists of backwashing and then pumping 1 % solution of caustic soda through the medium. After the removal of fluoride by the caustic soda, the excess caustic soda remaining in the bone char is removed. This is done by rinsing the bed with raw water until the pH of the effluent approaches that of the raw water (Mcharo, 1986).

Many experiments have been done on bone char with slightly different results. Filtration tests were done at Helsinki University in Finland using two sizes of crushed bone samples nearly free from fats and proteins. The raw water used was Helsinki tap water, which was fluoridated by using sodium fluoride. In the test the bone sample of 0.6 mm was soaked in a solution of sodium hydroxide (2 N) for 24 hours and then dried in an oven at 150 °C. In carrying out the experiments the water was stored in a 30 litre plastic container from which the water drained down through a rubber tube which was connected to a plastic filter 7.5 cm in diameter and 6 cm high with the rate of filtration adjusted to 15 L/h. After passing 23 L of water the 0.6 mm bone sample reduced fluoride from 4.56 to 4.18 mg/L. The extent of fluoride removal varied with the amount of bone used, contact time and the original concentration of fluoride in water. The finer bonechar, the greater removal of the fluoride, due to greater surface for contact. (Dhalla 1973 cited by Mcharo, 1986).

Other tests on bone char were done in Kenya in 1985. The preparation of bone char consisted of boiling the bones for about 3 hours in order to reduce the fats. This was followed by burning the bones for about 2 hours until they were completely charred. After the burning stage the bone charcoal was crushed to obtain the desired sizes. In these tests water containing known fluoride concentrations was allowed to flow through a water column of 150 mm diameter. The average rate of flow was 3.56 mL/s and in the first experiment fluoride was reduced from 17 mg/L to 1.1 mg/L after treating about 25 litres of water. In the second experiment fluoride was reduced from 6.6 mg/L to 0.38 mg/L after treating about 24 litres of water. In the second experiment regeneration was done by using 1 % solution of sodium hydroxide and in repeating the experiment fluoride was reduced from 6.6 mg/L to 0.95 mg/L after treating about 5 litres of water (Gitonga 1985 in Mcharo, 1986). One major advantage of the bone char method is the simplicity of getting the material. Bones are locally available. The main disadvantage is the dark colour from the char, which has to be removed before the treated water can be used for drinking. Defluoridation using bone char is also being experimented on at Ngurdoto Defluoridation Research Center in Arusha, Tanzania. In this method, clean cow bones are charred at 500 – 550 o C in specially designed kilns in which air supply is controlled. The charred bones are pulverized to particle sizes ranging from 0.5 to 3 mm in diameter. During defluoridation, the bone char particles are packed in either household or institutional level defluoridation plants. Raw water with a concentration of 10 mg/L fluoride can be treated to obtain a filtrate with fluoride less than 2 mg/L.

(2) Biological Method

Jamode et al., (2004) investigated the suitability of inexpensive leaf adsorbents to effectively remediate fluoride-contaminated water. They reported results from experimentation with leaves from neem (Azadirachta indica), pipal (Ficus religiosa) and khair (Acacia catechu willd) trees. This biological treatment method is based on the sorption (bioadsorption) process and is still under experimentation at laboratory scale. Their experiment is discussed hereunder.

i) Materials and Methods

All the reagents used were of AR grade. Fluoride stock solution was prepared by dissolving 221 mg anhydrous sodium fluoride in 1000 mL distilled water in volumetric flask. Fluoride standard solution was prepared by diluting 100 mL stock solution to 1000 mL distilled water in volumetric flask. This 1 mL solution has 0.1 mg of fluoride.

ii) Equipment

Fluoride ion was estimated by Orion ion meter as per standard methods. Remi shaking machine was used to agitate the samples at a speed of 200 strokes per minute. The surface area of the adsorbent particle, porosity and density were measured using surface area analyser, mercury porosimetry and specific gravity bottles, respectively.

iii) Material Development

Fresh leaves chosen based on their crude fibre content and trees were obtained from neem (Azadirachta indica), pipal (Ficus religiosa) and khair (Acacia catechu wild). The fresh leaves were sun-dried for 3 – 4 days, put in a cotton jute bag and crushed manually. The powder was sieved to get various particle sizes, viz. 600, 710, and 850μ, 1 mm, and 1.4 mm. Leaf powder biomass was further digested by chemical methods as described below.

iv) Acid Treatment

Leaf biomass powder sample (40 gm) and 400 mL of 1N HNO3 (nitric acid) were taken in a 1000 mL conical flask. The mixture was gently heated on a burner for 20 minutes after boiling started. Treated biomass was washed with distilled water until maximum color was removed and clear water obtained.

v) Alkali Treatment

Leaf biomass powder sample (40 gm) and 400 mL 0.5 N NaOH were taken in 1000 mL conical flask. Then the mixture was gently heated on a burner for 20 minutes after boiling started. Likewise, the treated biomass was washed with distilled water until maximum colour was removed and clear water obtained.

vi) Results

The efficiency of the sorption of fluoride ion is affected by pH, contact time, adsorbent dose, type and size of adsorbents and initial fluoride ion concentration. The adsorption equilibrium is well correlated by Freundlich and Langmuir models. Treated leaf powder was studied at pH 2, pH 4, pH 6 and pH 8, with a series of aqueous solutions containing 2, 3, 5, 6, 8, 10, 12, and 15 mg F–/L. At the highest F– ion concentration (i.e., 15 mg/L), the F– ion level in the effluent gradually decreased to 0 mg/L within 180 minutes at 29 ± 0.5 ^oC when the dose of adsorbent is 10 g/L in a sample of 50 mL volume. With lower F– ion concentrations (2 mg/L) in the feed solutions the fluoride ion concentration steadily decreased reaching 0 mg/L after 150 minutes. It was observed that Langmuir isotherm fits well for defluoridation of water using the leaf powder.

(3) Electro-dialysis Method

This is a membrane separation method that is used to remove dissolved salts from brackish water. The electrodialysis method, like the reverse osmosis method, is not practically intended for removal of fluoride from portable water. However, when fluoride is present in brackish water supply and the capital requirements are within the means of the community, these membrane separation methods are technically capable of delivering the desired treatment for water quality.

The process removes ionized salts from water by passing ions through ion permeable membrane by means of direct current electrical energy. The membranes are stacked in pairs of anionic and cationic permeable membranes. Raw water flows between the pairs through labyrinths which create turbulence while the direct current drives the anion through the anion permeable membrane and the cation through the cation permeable membrane. These anions are collected in a rejected stream which flows to waste or can be partially recycled. Similar to reverse osmosis method, the electrodialysis process is not selective but it removes all inorganic ions. It does not remove non-ionic dissolved solids or suspended solids. The fluoride level may be reduced from 7.0 mg/L to 1.4 mg/L (Rubel 1984 in Mcharo, 1986).

The electrodialysis method is expensive and complicated. Membrane maintenance is an economic drawback for this system. Presence of hardness, iron or manganese ions can further increase maintenance costs. Furthermore, it is an energy intensive process due to the current required to move the charged ions through their respective membranes.

(4) Factors Governing Costs of Defluoridation of Water

Defluoridation costs depend on many factors, the main ones are:

- Quality of raw water to be treated, e.g., pH value, presence of iron, manganese, arsenic, sodium, sulphates and presence of other organic and or inorganic contaminants that may reduce the efficiency of a treatment process.
- Treatment method applied for removing fluoride. Some methods involve complicated treatment plants that require high capital and operation costs.
- Initial concentration of fluoride in the raw water and the required residual concentration. High initial concentrations may need higher costs to reduce the fluoride level to the required value. This is due to higher consumption of chemicals and more frequent regeneration for the treatment media that gets saturated quicker for high initial fluoride values.

- Quantity of water to be treated. This governs the plant size and the amount of chemicals to be used.
- Availability of materials required for construction and operation of the treatment unit. Capital and operation costs may decrease if materials and chemicals are easily available. On the other hand, the costs will increase if the materials are to be imported.
- Labour requirements for the treatment system. Complicated plants require skilled manpower while the simple treatment systems may require ordinary skill in operating them thus resulting in cheaper operation.
- Location of the treatment plant. Plants in remote areas may need higher capital and operation costs due to difficulties involved in transporting the required materials. This has an impact also on the availability of power, which is essential for many treatment plants.

The experimented methods of fluoride removal have many factors to be considered before being accepted as the most appropriate methods to be adopted. Some of these methods are efficient but they are expensive and complicated which means that they would not be the best choice for a developing country. In analysing the costs of various methods, it is difficult to give exact costs because the factors governing treatment costs are variable for each project. Below is a comparison of some of these methods (Table 8-3).

Table 8-3 Comparison of Treatment Methods

No	Method	Working principle	Fluoride removal range	Treatment cost	Remarks
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.

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

At present there are no donors, NGOs or international organizations involved in activities pertaining to defluoridation of water in Tanzania (Personal communication with Mr. Mkongo, the resident technician at Ngurdoto Defluoridation Research Center, Arusha, Tanzania).

8.2. Water-related Diseases

8.2.1 Introduction

Water-related diseases are a human tragedy, killing millions of people each year, preventing millions more from leading healthy lives, and undermining development efforts (Olshansky, 1997). About 2.3 billion people in the world suffer from diseases that are linked to water (UNCSD, 1997). Some 60% of all infant mortality is linked to infectious and parasitic diseases, most of them water-related (Nash, 1993). In some countries water-related diseases make up a high proportion of all illnesses among both adults and children. Providing clean supplies of water and ensuring proper sanitation facilities would save millions of lives by reducing the prevalence of water-related diseases (UNCSD, 1997). Thus, finding solutions to these problems should become a high priority for developing countries and assistance agencies.

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

Water-borne diseases;
Water-washed (scarce) diseases;
Water-based diseases; and
Water-related vector diseases.

(1) Water-borne Diseases

Water-borne diseases are "dirty-water" diseases, those caused by water that has been contaminated by human, animal, or chemical wastes. Water-borne diseases include cholera, typhoid, shigellosis, polio, meningitis, and hepatitis A. The lack of sanitary waste disposal and clean water for drinking, cooking, washing and personal hygiene is the major cause of the spread of these diseases. Therefore, providing a clean water supply and improving public sanitation are the two steps needed to prevent most water-borne diseases and deaths. It is important that a clean water supply and the construction of proper sanitary facilities be provided together because they reinforce each other to limit the spread of infection.

(2) Water-washed (Scarce) Diseases

Water-washed diseases include trachoma (eye infection), skin diseases (e.g., scabies), leprosy, tetanus, and diphtheria. These diseases are considered water-scarce (also known as water-washed) in that they thrive in conditions where freshwater is scarce and sanitation is poor. Infections are transmitted when too little clean water is available for washing and personal hygiene. These diseases, which are rampant throughout most of the world, can be effectively controlled with better hygiene, for which adequate clean water is necessary.

(3) Water-based Diseases

Water-based diseases are caused by aquatic organisms that spend part of their life cycle in the water and another part as parasites of animals. These organisms can thrive in either polluted or unpolluted water. As parasites, they usually take the form of worms, using intermediate animal vectors such as snails to thrive, and then directly infecting humans either by boring through the skin or by being swallowed (Bradley, 1994). Water-based diseases include schistosomiasis (bilharzia), guinea worm (dracunculiasis), paragonimiasis, and clonorchiasis. These diseases are caused by a variety of flukes, tapeworms, roundworms and tissue nematodes, often collectively referred to as helminths that infect humans (Muller and Morera, 1994). Although these diseases usually are not fatal, they can be extremely painful, preventing people from working and sometimes even making movement impossible.

Individuals can prevent infection from water-based diseases by washing vegetables in clean water and thoroughly cooking food. They can refrain from entering infected rivers, because many parasites bore through the feet and legs. As with water-washed diseases, providing hygienic disposal of human wastes helps control water-based diseases.

(4) Water-related Vector Diseases

Water-related vector diseases are infections that are transmitted by vector insects or other animals capable of transmitting an infection, such as mosquitoes and tsetse flies that breed and live in or near both polluted and unpolluted water. Such vectors infect humans with malaria, yellow fever, dengue fever, sleeping sickness, and filariasis.

Lack of appropriate water management, along with failure to take preventive measures, contributes to the rising incidence of malaria, filariasis, and onchocerciasis. Construction projects often increase the mosquito population, as pools of stagnant water, even if they exist only briefly, become breeding grounds (Hunter et al., 1993).

The solution to water-related vector diseases would appear to be eliminating the insects that transmit the diseases. This is easier said than done, however, as pesticides themselves may be harmful to health if they get into drinking water or irrigation water. Also, many insects develop resistance to pesticides, and diseases can emerge again in new forms (Olshansky, et al., 1997). Alternative techniques to control these diseases include the use of bednets, introducing natural predators and sterile insects, and eliminating mosquito-breeding sites.

8.2.2 Situation of Water-related Diseases in Study Areas

The data available at the Ministry of Health regarding water-related diseases are limited to the recent years (i.e. 2003 to 2005). However, they give a good indication of prevalence of water-related disease in the study regions.

Tables 8-4, 8-5 and 8-6 present cumulative data of water-borne diseases (i.e., cholera, dysentery, diarrhoea and typhoid) in the study regions. According to the number of reported cases and the corresponding deaths, diarrhoeal diseases are leading in all regions followed by dysentery. This is probably attributed to inadequate clean supplies of water, pollution of water supplies owing to poor sanitary conditions, as well as poor personal hygiene. It is also noted that from year 2003 to 2005 (Tables 8-4 to 8-6) Shinyanga and Dodoma regions had the highest number of reported cases of diarrhoeal and dysentery diseases, respectively.

Table 8-4 Cumulative Reported Cases of Water-borne Diseases in the Study Regions in 2003 (Ministry of Health)

Regoin	Cholera		Diarrhoea		Dysentery		Typhoid	
	Cases	Dead	Cases	Dead	Cases	Dead	Cases	Dead
Arusha/ Manyara	325	3	9320	16	1867	2	2013	8
Dodoma	364	5	23781	19	7520	1	1461	0
Shinyanga	137	3	49468	31	2353	1	2904	4
Singida	32	2	8659	3	1485	3	663	0
Tabora	0	0	10054	22	1009	3	913	2

Table 8-5 Cumulative Reported Cases of Water-borne Diseases in the Study Regions in 2004 (Ministry of Health)

Region	Cholera		Diarrhoea		Dysentery		Typhoid	
	Cases	Dead	Cases	Dead	Cases	Dead	Cases	Dead
Arusha	487	1	8926	22	1299	5	1340	1
Dodoma	299	13	34406	40	6559	2	1906	0
Manyara	360	5	8141	14	2318	3	468	2
Shinyanga	1	0	56044	20	3339	0	2454	5
Singida	45	0	11873	3	1360	1	2010	0
Tabora	4	0	19959	29	1602	7	1292	0

Table 8-6 Cumulative Reported Cases of Water-borne Diseases in the Study Regions in 2005 (Ministry of Health)

Region	Cholera		Diarrhoea		Dysentery		Typhoid	
	Cases	Dead	Cases	Dead	Cases	Dead	Cases	Dead
Arusha	70	0	7149	21	1876	1	1102	0
Dodoma	295	9	24983	3	3444	3	1368	1
Manyara	0	0	11612	14	1704	3	733	5
Shinyanga	0	0	34080	5	2560	0	1256	1
Singida	0	0	4667	7	561	3	1016	0
Tabora	0	0	11975	18	721	9	386	1

During this study, data pertaining to the number of cases of water-related diseases (malaria, diarrhoea, intestinal worms, eye infections, skin infections, and schistosomiasis), reported as incidence, were available for year 2004 only. These data were for Arusha, Dodoma, Manyara and Tabora regions (Figures 8-6, 8-7, 8-8 and 8-9).

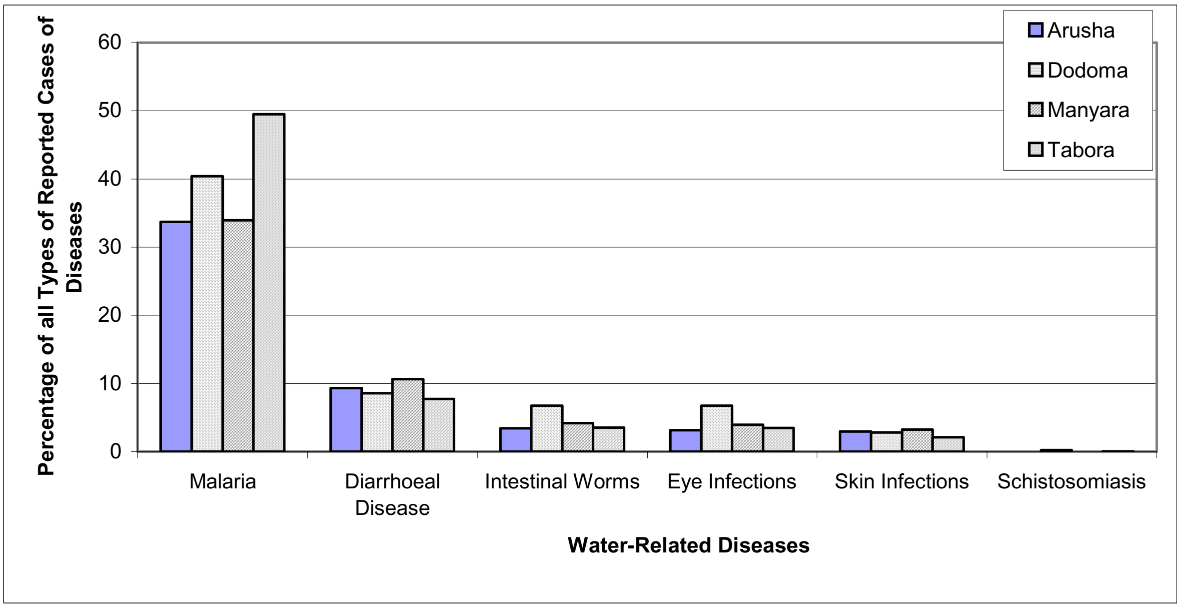


Figure 8-6 Occurrence of Water-related Diseases for Out-patients Aged below 5 Years
(A total of 30 types of diseases were reported. Note that non-water related diseases are not presented, hence the percentage does not add up to 100. (Ministry of Health, 2004).)

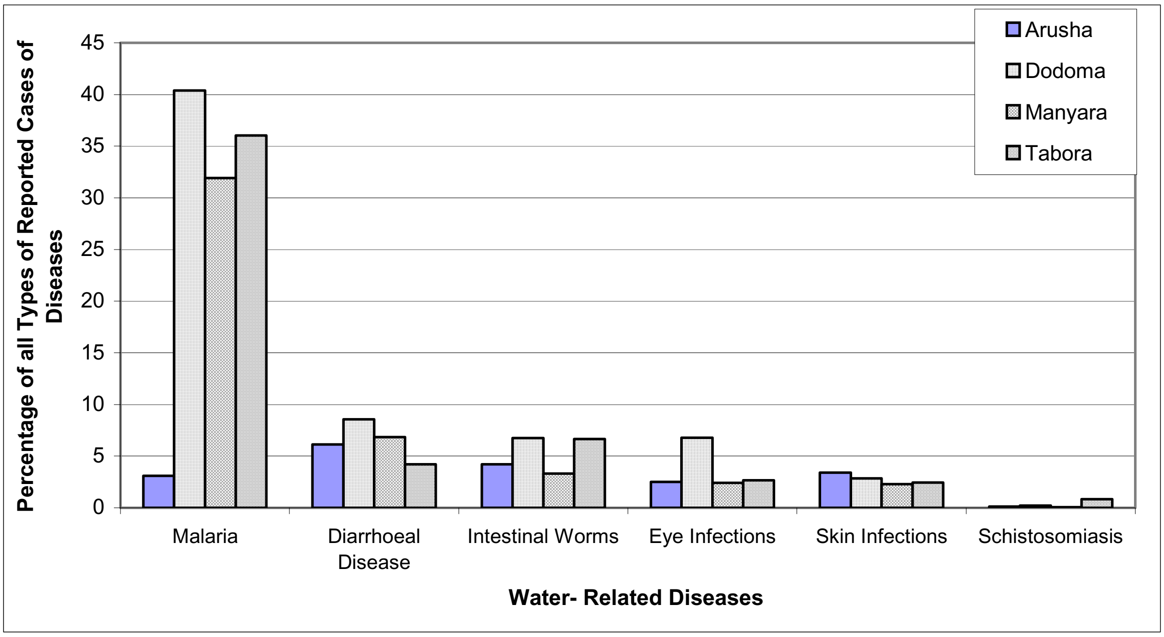


Figure 8-7 Occurrences of Water-related Diseases for <u>Out-patients Aged above 5 Years</u>
(A total of 42 types of diseases were reported. Note that non-water related diseases are not presented, hence the percentage does not add up to 100 (Ministry of Health, 2004).

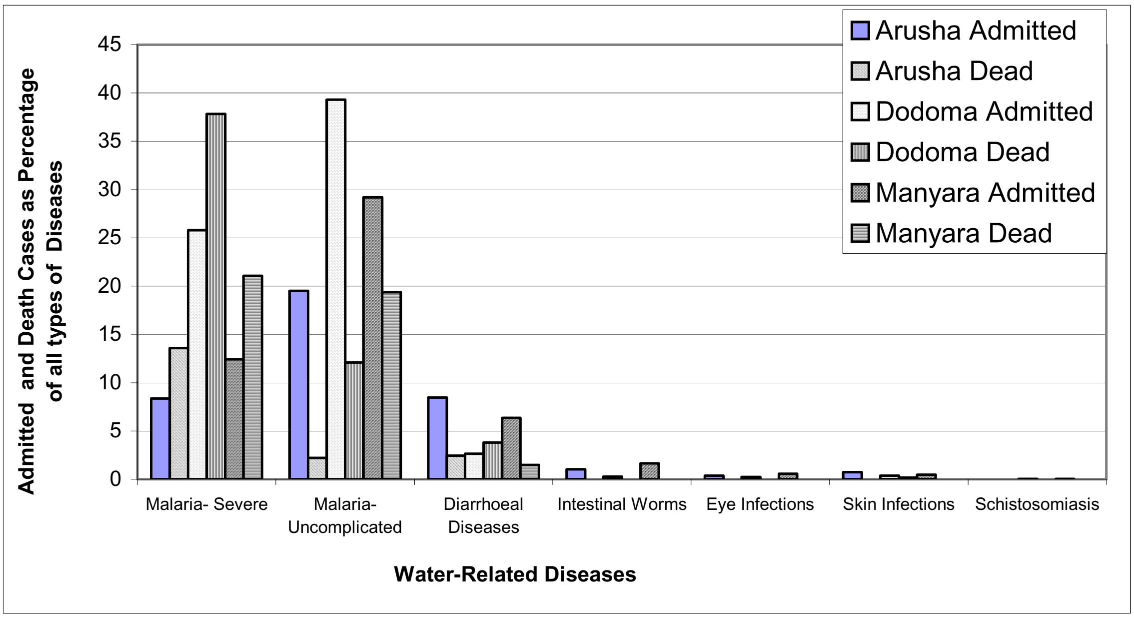


Figure 8-8 Occurrences of Water-related Diseases for <u>Admitted Patients Aged below 5 Years</u>
(Corresponding cases of dead patients are also presented. A total of 40 types of diseases were reported. Note that non-water related diseases are not presented, hence the percentage does not add up to 100 (Ministry of Health, 2004).)

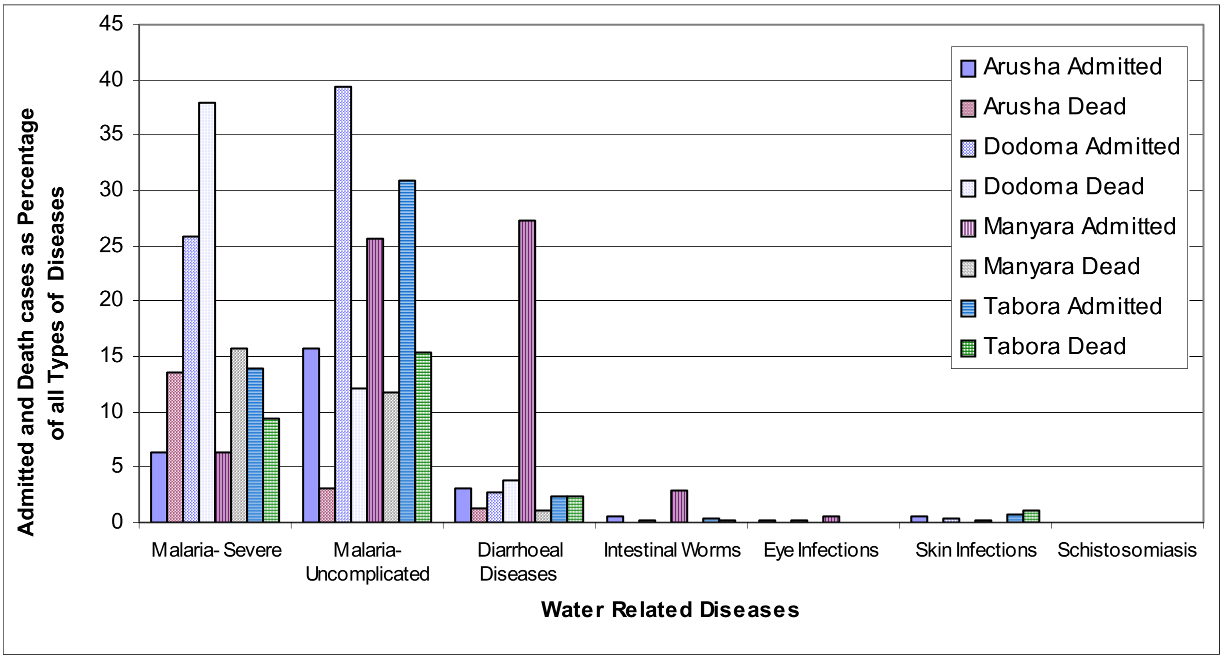


Figure 8-9 Occurrences of Water-related Diseases for Admitted Patients Aged above 5 Years
(Corresponding cases of dead patients are also presented. A total of 51 types of diseases were reported. Note that non-water related diseases are not presented, hence the percentage does not add up to 100 (Ministry of Health, 2004).)

It is observed that the largest proportions of the reported cases in the regions are attributed to malaria, diarrhea diseases, and intestinal worms. Figures 8-6 and 8-7 also indicate that Dodoma region had the highest proportion of eye infections. As stated earlier, eye infections thrive in areas where freshwater is scarce and sanitation is poor. Thus, these conditions are probably the cause of incidence of these diseases in Dodoma. Figures 8-6 and 8-7 also show that the proportion of reported cases of skin infections did not differ significantly among the four regions.

8.3 Dental Fluorosis in Internal Drainage Basin (IDB)

8.3.1 Introduction

In Tanzania both dental and skeletal fluorosis are recognized health problems, more so for populations living along the Great Rift Valley. Of the regions that are in the Great Rift Valley, some belong to the Internal Drainage Basin. These include Arusha, Dodoma, Manyara, Shinyanga, Singida and Tabora. About 90% of the population in these regions are reported to be affected by dental fluorosis at varying severity or stages. The National Plan for Oral Health 1988 – 2002 points at the very high prevalence of severe endemic dental fluorosis in Arusha, Kilimanjaro, Shinyanga, Singida and Tabora regions. As such, the Tanzania Food and Drugs Authority categorized dental fluorosis as the 5th most common nutritional disorder in the country. Besides severe dental fluorosis in permanent teeth, fluorosis in deciduous dentition and skeletal fluorosis has been reported in Arusha Region. Similarly, the Ministry of Health and Social Welfare has set a goal which aims at looking for appropriate methods of reducing excessive fluoride intake in fluoride endemic areas, the ultimate objective being to reduce or stem dental and skeletal fluorosis in Tanzania.

Dental fluorosis is caused by chronic ingestion of fluoride higher than 1.5mg/L during the formative stages of dental hard tissues. The length of exposure, frequency of ingestion and ingested fluoride dose determine the plasma fluoride steady state (PFSS), which in turn influences the severity of dental and skeletal fluorosis of an individual. The severity of dental fluorosis can range from only narrow white lines along the perikymata or small surface areas of the enamel with diffuse borders to pitting and loss of enamel, which may include changes in the anatomic appearance of the affected teeth In the situation of mild or slight dental fluorosis, the enamel surface is usually hard and smooth, whereas in its severe forms, especially if the uptake of high doses prevailed during all the phases of enamel development, enamel pitting and gross wear of the enamel are usually observed, which in certain instances result into loss of anatomical morphology of the tooth. The severe forms of dental fluorosis are usually accompanied with secondary staining, which is due to incorporation of organic salivary compounds, bacterial material and food substances. Such staining is often aesthetically objectionable. A number of psychosocial factors are linked to this aesthetical setback.

Psychosocial factors reflect how people make sense of their social environments. These; to mention only a few include awareness, knowledge, and perceptions like opinions, beliefs, and attitudes. In one way or another, these factors determine the propensity for people to behave in a certain way. Exploring psychosocial factors which are related to dental fluorosis greatly enhances the precision in planning for intervention programs.

Chronic ingestion of fluoride above 3.6 mg/L can lead to skeletal fluorosis. There are two stages of skeletal fluorosis, asymptomatic and crippling skeletal fluorosis. Asymptomatic skeletal fluorosis, is the early stage and less advanced form, which often goes undetected as the affected individuals usually continue with their normal life activities without complains. The advanced form of skeletal fluorosis also called crippling skeletal fluorosis occurs in most cases with mineral deficiencies and malnutrition. Individuals affected with crippling skeletal fluorosis show signs of stiffness of the spine and in most cases suffer from limitation of free movement, advancing kyphosis and flexion deformities of the knees. The health, economic and social impacts of skeletal fluorosis are: (1) invalidation of life, (2) long life suffering, (3) loss of quality of life/productivity and (4) dependence on others. Nevertheless, assessment of skeletal fluorosis involves more complicated and sometimes invasive procedures. For this reason most workers pressed with a need to study the effect of excessive fluoride intake would opt to check on dental fluorosis, as a first indicative marker of fluoride poisoning.

The WHO recommends F^- concentration of 1.5 mgF^-/L as the acceptable upper limit which can vary depending on other factors like climate, other sources of Fluoride etc. In hot climate countries where the consumption of water is high much lower levels of 1.0 mgF^-/L or less are recommended. The 1.5 mgF^-/L concentration is considered to be the optimal level that is likely to cause minimum level of socially unacceptable dental fluorosis and it is this same level which offers maximum protection of teeth against dental caries.

Faced with the challenge of supplying safe drinking water to communities in arid areas of Tanzania, the Government had to set 8 mgF^-/L as a temporary standard of fluoride concentration in drinking water since 1970[20] (Rural Water Supply Standard Committee 1974), and later 4 mgF^-/L in 2003 by Tanzania Bureau of Standards TBS) . However, in most endemic areas of Tanzania exposure to such high fluoride in drinking water is also complicated by a salt magadi (Sodium carbonate and sodium bicarbonate). Studies done in Singida and Kilimanjaro Regions in Tanzania have established that magadi is another source of fluoride. Magadi, - is a trona (Sodium carbonate and sodium bicarbonate), which is often as a food tenderiser and for speeding cooking time. The salt may be contaminated with F^- ions to varying concentrations depending on the source.

Bearing in mind the wide use of magadi and its varying fluoride concentrations and that some communities may be exposed to excessive fluoride from both water and magadi, it is possible that the total fluoride ingestion is much higher than considered. Therefore for characterization of an area with respect to fluoride, both drinking water and magadi fluoride concentration should be determined.

The situation is rather complicated in some parts of Northern and Central Tanzania especially the regions in the Internal Drainage Basin, as many water sources contain high Fluoride more than 4 mg/L which has been set since 2004 as a temporary standard by the Government of Tanzania. The wide use of magadi in some populations of Tanzania, whose drinking water contains F conc. above 1.5 mg/L, complicates this situation.

Teeth with severe dental fluorosis can negatively affect individual's ability to interact and form relationships. Such negative effect may lead to exclusion, loneliness and long-term depression, which in turn could then result into feelings of frustration and other undesirable social behaviour. On the other hand, lack of correct information on the causes of dental fluorosis among some individuals could intensify the problem, as they would continue to ingest water and magadi from high fluoride sources even when alternatives were availed. Peoples' perception of the magnitude of the problem has a bearing on the likelihood that they would be willing to participate in the elimination of the problem.

Considering that the people who are living in the fluoride endemic areas are likely to be ingesting much higher doses of fluoride above the maximum recommended level of 1.5 mg/L, the need for urgent intervention cannot be overstressed.

As a prelude to intervention activities and for planning short term and long term intervention strategies there is need to determine (a) the prevalence and severity of dental fluorosis (b) the population awareness, knowledge and perceptions on dental fluorosis and (c) the possibilities of mobilizing the community at risk in the planning and implementation of intervention activities must be investigated.

Therefore this health survey project aimed at addressing the health effects of fluoride ingested from drinking water and from use of 'magadi' (trona). The data obtained from this survey was expected to estimate the prevalence of fluorosis and explain the relationship between the level of fluoride ingested and the severity of the problem fluorosis of people living in Internal Drainage Basin.

The Internal Drainage Basin is an area that is situated in the north-eastern part of Tanzania comprising of six regions namely, Arusha, Shinyanga, Manyara, Dodoma, Singida and Tabora. The Internal Drainage Basin covers an area of 143,000 km^2 and is estimated to have a total population of about 5 million.

Besides water being very scarce in this area, there are also water quality problems which are due to the internal drainage system which leads to accumulation of various inorganic salts or other materials hazardous to health of human beings. Example of such materials is fluoride in surface and groundwater.

From the foresaid water resources development, particularly, the development of ground water system is an urgent issue of concern toward provision of safe and stable water supply in this area of the Internal Drainage Basin.

In order to achieve such an important goal, management of data and information related to the existing water supply facilities, hydrology, geomorphology, water quality, social-economy, health status of the population and other related data have to be integrated. It is with this background that, among a number of objectives of the study on Groundwater Resources Development and Management in the Internal Drainage Basin (IDB) by JICA is to address the problem of fluoride contamination in the water in respect to the health of the people living in this area.

Nevertheless, information on the extent of health problems caused by ingestion of high fluoride in Tanzania is scanty. Such information is available from only a few localities/villages of Arusha, Kilimanjaro, and Singida regions. This study will provided baseline information which was lacking, This information is important for planning intervention programs, as such this is first extensive study to provide information on the exposure to fluoride, sources of fluoride to communities, the magnitude of dental fluorosis, and population psychosocial factors linked to dental fluorosis. As such its importance cannot be overemphasized. The aim of study therefore was to determine the prevalence and severity of dental fluorosis and the community psychosocial factors related to fluorotic teeth in the six regions of the Internal Drainage Basin.

The specific objectives of the study were to:

- ✓ Determine the prevalence and severity of dental fluorosis according to fluoride concentration in water and Magadi.
- ✓ Determine the population perception about dental fluorosis and their willingness to participate in an intervention against dental fluorosis.
- ✓ Determine the knowledge of study participants on the causes of dental fluorosis.

8.3.2 Materials and Methods

This study was conducted in the Internal Drainage Basin (IDB), which is situated in the Northern-central part of Tanzania and is comprised of six regions namely, Arusha, Shinyanga, Manyara, Dodoma, Singida and Tabora. From the six regions 18 districts were chosen based on their water fluoride levels being higher than 1.5mg/L. Then 96 villages were selected based on i) stability of the population with most people having been born and lived all their lives there and ii) that these villages must have had permanent water sources that have been in constant use for a period of at least 15 years. In each of the selected villages, one school was randomly chosen. In each school 15 boys and 15 girls whose age ranged from 12-18 years old and who were born and lived in the selected village were picked by quota sampling. Two thousand eight hundred and eighty (2,880) adolescents were targeted nevertheless 2,912 children turned up for the survey. The small addition in sample size was tolerated, as it would not have a significant influence on statistical computations.

Fluoride level in the water was available from 91 out of the 96 study villages. Magadi samples were analysed from 85 out of the 96 study villages. The findings of this analysis were incorporated into the dental fluorosis data file for studying the relationship between dental fluorosis and fluoride levels in water and magadi. All examiners were trained and calibrated prior the commencement of the survey.

Dental fluorosis was diagnosed and scored using the Thylstrup Fejerskov Index (TFI) of Dental fluorosis. This Index was chosen because of its high reproducibility and error coefficient[23]. TFI has the ability to recognize the very mild forms of dental fluorosis as such it can be used to detect dental fluorosis in low fluorosis areas compared to the other indices[23]. The prevalence and severity of dental fluorosis according to the TFI individual scores was used to determine the level of exposure to fluoride and to make comparison between different communities under this study.

Training and calibration in progress

1. The Thylstrup Fejerskov Index (1978) was used to diagnose and score dental fluorosis (Table 8-1).
2. The clinical examination followed precisely the prescribed procedure, i.e. the surfaces were isolated using sterile

gauze and dried by a sterile cotton wool. Scoring of the tooth surface was done 2 minutes after drying the teeth.

3. A full mouth examination was carried out for each individual who consented to participate in the study i.e. for all maxillary teeth, from molar (17) to molar (27) and for mandibular teeth from molar (37) to molar (47) were be examined.
4. Because of the similar pattern of the effect of fluoride to all tooth surfaces, only buccal surface of each tooth were scored, furthermore buccal surfaces are less subjected to wear and tear as compared to occlusal surfaces.
5. Each examined buccal surface was diagnosed and scored according to the TFI criteria as presented below (Table 8-7).

Table 8-7 Thylstrup and Fejerskov Index – Diagnostic Criteria for Dental Fluorosis Scores

Score	Criteria
0	Normal translucency of enamel remains after prolonged air-drying.
1	Narrow white lines corresponding to the perikymata.
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.
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.
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.
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

All the information was filled in the clinical survey form (Table 8-8).

Table 8-8 Clinical Form For Dental Fluorosis for the 12 - 18 Years Subjects

PERSONAL PARTICULARS

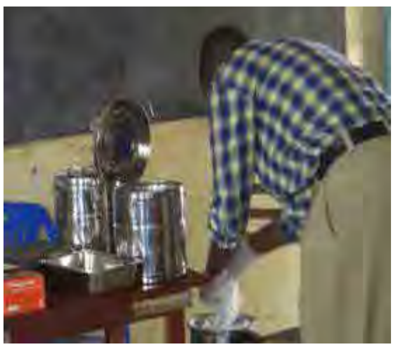
Region
District
Division
Ward
Village
ID. No of interviewee
Age of the respondent
Sex

Duration of stay in the village (years)

1.2 CLINICAL EXAMINATION

MAXILLARY TEETH	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
TFI SCORE BUCCAL SURFACE														
MANDIBULAR TEETH	**37**	**36**	**35**	**34**	**33**	**32**	**31**	**41**	**42**	**43**	**44**	**45**	**46**	**47**
TFI SCORE BUCCAL SURFACE														

Clinical examination was done with examiners putting on examination disposable gloves and masks. Children were placed on examiner's lap and natural light was used in a classroom. All examination instruments and gauze were steam sterilised using pressure cookers. Sterile instruments were stored in sterile containers. To ensure high levels of sterility and instil trust among the participants who were examined, instruments were sterilised prior and after the examination at each workstation.



Sterilization in progress

Information regarding awareness, knowledge and perception as attitudes and beliefs about dental fluorosis was collected before the clinical examination using structured questionnaires (English version, Appendix II & Swahili version Appendix II). Seven, five-point scaled questions were used to measure the psychosocial impact of dental fluorosis. These were analysed separately and then were additively combined to obtain a summative index for perception. Knowledge was assessed by using 9 questions each measured on a dichotomised scale. Both survey instruments were field tested in Kibosho Moshi with acceptable levels of validity and reliability.



Interview in progress

Data Analysis

The data was processed and analysed by using SPSS program version 13. Frequency distributions were run to check for any inconsistencies and study the data patterns. Bi-variate analysis was done using Chi square, t-test, ANOVA and correlation coefficients.

Approval to conduct this study and ethical clearance was obtained from the National Medical Research Institute (NIMR) of the Ministry of Health. An introductory letter from the Internal Drainage Basin headquarters was circulated to Permanent Secretaries, Ministry of Water and Ministry of Education, Regional Administrative Secretaries (RAS), and District Executive Directors (DED) of respective Regions and Districts The study purpose of the study was explained to the Regional, District, Division and Ward administrative authorities before visiting the specific schools in the sampled villages. Only after receiving permission from the said authorities, visits to the schools were made. The purpose of the study was explained to the school teachers, study participants and village leadership. After understanding and consenting to participate in this study, the participants were interviewed and later examined for dental fluorosis.


Dental examination for fluorosis in progress

8.3.3 Results

(1) Demographic Information

A total of 96 villages drawn from six regions of the internal drainage basin involved 2912 school children of which 49.2% were males (Table 8-9). Of the 96 villages, half of them are located at an altitude of 1178 meters above see level (Table 8-10). The lowest altitude; 980 meters above see level was recorded at Lukali village, in Dodoma and the highest was at 1890 meters above see level recorded at Lemong'o village in Arusha region.

Table 8-9 Distribution of Children by Age, Sex and Regions

Region	Age	Males		Female		Total	
		number	%	number	%	number	%
Arusha	14 yrs or less	36	46.2	57	79.2	93	79.2
	15yrs or above	42	53.8	15	20.8	57	38.0
	Sub-Total	**78**	**100**	**72**	**100**	**150**	**100%**
Dodoma	14 yrs or less	23	46.9	24	57.1	47	51.6
	15yrs or above	26	53.1	18	42.9	44	48.4
	Sub- Total	**49**	**100**	**42**	**100**	**91**	**100**
Manyara	14 yrs or less	70	42.9	74	44.3	144	43.6
	15yrs or above	93	57.1	93	55.7	186	56.4
	Sub-Total	**163**	**100**	**167**	**100**	**330**	**100**
Singida	14 yrs or less	231	50.9	345	70.8	576	61.2
	15yrs or above	223	49.1	142	29.2	365	38.8
	Sub- Total	**454**	**100**	**487**	**100**	**941**	**100**
Shinyanga	14 yrs or less	252	41.2	381	60.1	633	50.8
	15yrs or above	359	58.8	253	39.9	612	49.2
	Sub-Total	**611**	**100**	**634**	**100**	**1245**	**100**
Tabora	14 yrs or less	51	64.6	61	80.3	112	72.3
	15yrs or above	28	35.4	15	19.7	43	27.7
	Sub-Total	**79**	**100**	**76**	**100**	**155**	**100**
Total		**1434**	**49.2**	**1478**	**50.8**	**2912**	**100**

The age of children ranged from 8-18 years. The age was dichotomised to two categories including 8-14 years (55.1%) and 15 years and above (Table 8-9). Ninety-five of the villages that were visited had schools that were fully established with classes 1-7. One school namely; Endanyawish in Mbulu district had only standard 1 and 2 from which children with age as low as 8 years were included in the sample. However, these children who were below 12 years constituted only 0.3% of the total sample.

Table 8-10 Distribution of Study Participants by Altitude in Meters Above Sea Level

Metres above sea level	Number of children	%
968 - 1104	724	25.9
1105 - 1178	697	25.0
1185 - 1398	678	24.3
1400 - 1890	693	24.8
Total	**2792**	**100.0**

(2) Fluoride levels in drinking water

Water samples were collected and analysed, thereafter the fluoride concentration results were incorporated to the data file for this study in order to assess the association of fluoride concentration and dental fluorosis. It was possible to get water sample results from 91 villages. From each village only one source was used to collect water sample. However, questionnaire results indicated that several water sources were normally used by villagers during the year. Fluoride levels in the water ranged from 1.5 to 24.9 mgF^-/l (Table 8-11). Fifty percent of the children were residing in villages where at least one of the water sources had fluoride levels of less than 4.0 mgF^-/l. Less than one fifth (18.9%) of the children lived in villages that had at least one source of water with fluoride levels of less than 2.0 mg/L. Twenty five percent of the children lived in areas with at least one source of water having fluoride levels of 6.4 mgF^-/L or more. None of the water sources whose samples were assessed had WHO standard of 1.5 mgF^-/L of fluoride in drinking water. The overall mean fluoride concentration in the internal drainage basin was 4.6 mgF^-/L.

Table 8-11 Distribution of Fluoride Concentration in Water by Regions

Regions	Number of villages	Mean F(mg/L)	Range F(mg/L)	
			Minimum	Maximum
Arusha	5	4.200	2.0	7.1
Dodoma	3	2.159	1.5	2.5
Manyara	6	2.500	1.5	4.0
Singida	31	5.646	1.5	16.1
Shinyanga	41	4.780	1.5	24.9
Tabora	5	2.400	1.5	3.0
Total	**91**	**4.675**	**1.5**	**24.9**

Table 8-12 Distribution of Children and Fluoride Concentration in Water by Regions

Regions	Fluoride level (mg/L)				
	1.5 - 2.5	2.6 - 3.8	4.0 - 6.7	7^+	**Total**
Arusha	60 (40%)	0(0%)	60(40%)	30(20%)	150(100%)
Dodoma	91(100%)	0(0%)	0(0%)	0(0%)	91(100%)
Manyara	90(50%)	60(33.3%)	30(16.7%)	0(0%)	180(100%)
Singida	152(16.2%)	63(6.7%)	515(54.7%)	211(22.4%)	941(100%)
Shinyanga	394(31.6%)	335(26.9%)	272(21.8%)	244(19.6%)	1245(100%)
Tabora	62(40.0%)	93(60.0%)	0(0%)	0(0%)	155(100%)
Total	**849(30.7%)**	**551(19.9%)**	**877(31.8%)**	**485(17.6%)**	**2762(100%)**

It is worth noting that questionnaire results indicated that the most prevalent water source was shallow wells (48%) while only 2.1 % of the 92 water samples were from shallow wells (Table 8-13). On the other hand, boreholes were the most prevalent water source tested in the 96 villages where dental survey was carried out. It is evident from responses obtained from children during dental examination for fluorosis that there were several water sources in each village and that taking only one sample from each village might not have captured the true reflection of fluoride exposure to the inhabitants of that area. It was also found that, in cases where borehole water had exceeding amount of fluoride, villagers opted not to drink nor cook with such water. The villagers had condemned the water source as not suitable for human consumption. One such example is Gula village (upper left photo) in Maswa district where the borehole dug by a Christian Roman Catholic Organization was established to be used for washing only. The water had strange taste and odour, with a record of 24.9 mg/L. Nearby this source, the villagers were found fetching water from a seasonal river for domestic use. The later was collected during dental fluorosis study and had fluoride level of 14mg/L. This emphasizes that even shallow waters in IDB area are likely to contain unacceptable amount of fluoride.

This water source is for washing only, Gula village.

Gula - borehole used for washing only ($24.9\ mgF^-/L$)

Gula – shallow well source for drinking and cooking

Likewise, a possibility exists that most boreholes were recently constructed and their effect on the prevalence and severity of dental fluorosis is yet to be recorded in some years to come. Where an element of cost sharing in running the boreholes comes into picture, some villagers would as well opt for other free of charge water sources. Therefore, boreholes might be there but people would use them as an alternative water source rather than regular sources. Tallying the most prevalent water source as reported by children and the prevalent water source analyzed for fluoride indicated that there was concordance in only 21%. This implies that the water samples were possibly taken from sources that were used by only a number of participants. Further more, the study shows that about 50% of study participants live in areas where fluoride level in the water is more than 3mg/L, a temporary standard set by Tanzania Bureau of Standards (TBS)

Table 8-13 Distribution of water sources that were analyzed for fluoride levels

	Number of children	Percentage
Spring	361	12.9
Pond	30	1.1
Shallow well	60	2.1
River	424	15.2
water hole	182	6.5
Bore hole	1249	44.7
Dug well	332	11.9
Dam	124	4.4
Stream	30	1.1
Total	**2792**	**100.0**

(3) Fluoride levels in magadi samples

A total of 90 magadi samples were collected from 85 villages. The analysis result was shown in Table 8-14. After analysis the fluoride concentration results of magadi were incorporated to the data file for this study in order to assess the association of fluoride concentration and dental fluorosis. The levels ranged from 2.7-31,000 mgF^{-}/kg. The samples with highest fluoride concentration were from Kidarafa village whereas the lowest concentration came from Mwando, both located in Iramba District. Arusha region had the highest mean fluoride concentration in magadi (12,659.5 mgF^{-}/kg) and the lowest mean were magadi samples from Manyara region. However, it was also noted that in villages where there were more than one samples analysed, the fluoride contents were remarkably different, for example the two samples from Oldonyosambu in Arumeru district had 8,500 and 23,000 mgF^{-}/kg F- concentration, respectively. Another example was the samples taken from two different household in Masela (Maswa district), one read 1,642 mgF^{-}/kg, but another read 2,628 mgF^{-}/kg. This strongly implies that the villagers in the same village are most likely accessing magadi from different sources. This makes the correlation of fluoride in magadi versus dental fluorosis more complicated than previous thought.

Table 8-14 Distribution of Fluoride Concentration in Magadi Samples by Regions

Regions	No. of Samples	Mean F (mg/kg)	Range F(mg/kg)	
			Minimum	Maximum
Arusha	4	12,659.50	1,138.00	23,000.00
Dodoma	3	2,025.33	54.00	5,978.00
Manyara	7	222.04	3.93	1,199.00
Shinyanga	39	2,648.00	4.00	12,074.00
Singida	32	3,636.00	2.70	31,000.00
Tabora	5	3,455.33	46.00	11,000.00
Total	**90**	**3,455.00**	**2.70**	**31,000.00**

(4) Dental Fluorosis Status

All 2,912 children were examined for dental Fluorosis using the TFI. All third molars i.e. the wisdom teeth are usually not examined when the TFI is used. Therefore these were also not examined in this study. The TFI Scores ranged from 0 (no Fluorosis) to 9 (most severe form of Fluorosis). In order to avoid over-scoring, teeth that were tempered with by grinding or other forms of mutilations were excluded from examination. Teeth that were fully covered with calculus were also excluded from the TFI analysis. All the scores obtained from each tooth were added up to form an additive or summative index. The summative index summarises the contribution of each tooth score to the overall score for each individual for a maximum of 28 teeth that were examined per child. The summative index allows for computation of average scores which enrich the expression of dental fluorosis severity.

The overall prevalence of dental fluorosis was 96.3%. Arusha region had the highest prevalence of dental fluorosis (100%), followed by Manyara (99.7%), the lowest prevalence was 92.3% recoded in Dodoma region. Analysis of prevalence by district revealed that; Arumeru, Babati, Manyoni, Mbulu, Meatu, Monduli

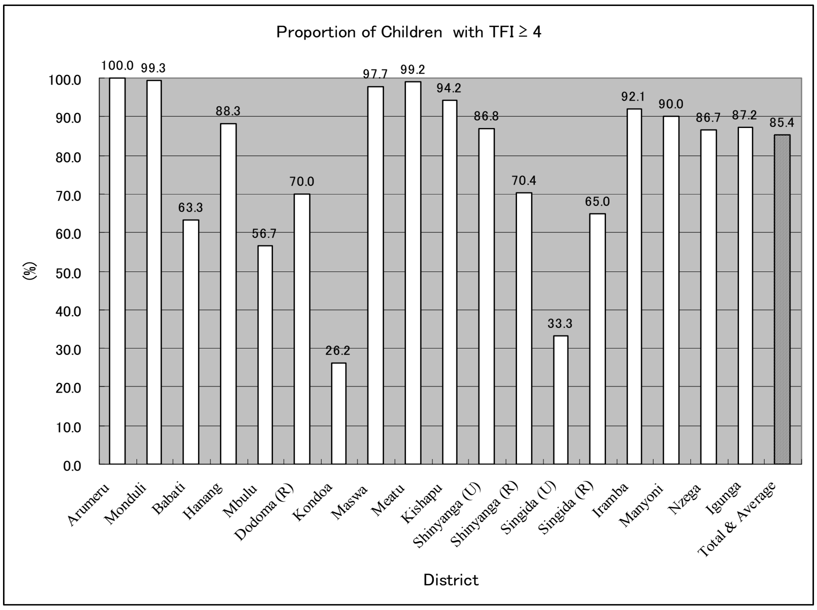


Figure 8-10 Proportion of Children with TFI > 4 by District

and Nzega had prevalence of 100%. Dodoma, Hanang, Igunga, Iramba, Kishapu and Maswa districts had prevalence higher than 90%. The lowest prevalence (79.7%) was recorded in Singida -Urban (See Figure 8-10).

Table 8-15 Distribution of Children with TFI ≥ 4 by District

Districts	Number of all children (N)	Number of children with TFI ≥ 4	Proportion of children with TFI ≥ 4
Arumeru	60	60	100.0
Babati	60	38	63.3
Dodoma (R)	30	21	70.0
Hanang	240	212	88.3
Igunga	125	109	87.2
Iramba	545	502	92.1
Kishapu	606	289	94.2
Kondoa	61	16	26.2
Manyoni	60	54	90.0
Maswa	213	208	97.7
Mbulu	30	17	56.7
Meatu	362	359	99.2
Monduli	90	84	99.3
Nzega	30	26	86.7
Shinyanga (R)	213	150	70.4
Shinyanga (U)	151	131	86.8
Singida (R)	306	199	65.0
Singida (U)	30	10	33.3
Total	**2912**	**2485**	**85.35**

Majority of teeth scored TFI 3 to TFI 7. Exploration of the data further revealed that 85.3% of the children had at least one tooth with TFI score of greater than or equal to 4. TFI score 4 indicates that the entire surface exhibits marked opacity or appears chalky white. Seventy five percent (75%) had at least one tooth with TFI score greater than 5. TFI score 5 indicates that the entire surface displays marked opacity with focal

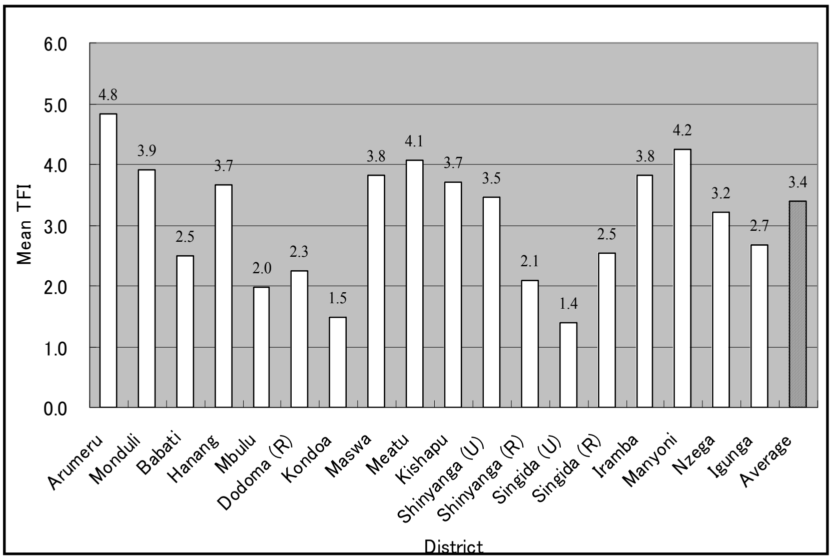


Figure 8-11 Mean TFI by District

loss of outermost enamel pits of less than 2 mm in diameter. More than forty one percent (41.4%) had at least one tooth with TFI score greater or equal to 7. TFI score 7 indicates that there is loss of outermost enamel in irregular areas which involves about half of the entire tooth smooth surface.

Taking TFI score≥ 4 as a point of departure to severe forms of dental fluorosis, the data was analysed by districts. Arumeru had 100% of individuals with one tooth scoring TFI score ≥ 4, followed by Iramba, Kishapu, Manyoni, Maswa and Monduli whose proportions ranged from 90-99.3%. The lowest proportion was recorded in Singida- Urban (See Figure 8-11).

The severity of dental fluorosis by tooth type was as follows: The least affected teeth were incisors with their TFI scores ranging from 1.9-2.4 (mean 2.4), followed by canines 3.1-3.3 (mean 3.23), premolars 3.8-3.9 (mean 3.87), first molars 3.7-4.2 (mean 4.09) and second molars 3.8-4.46 (4.14). The summative index ranged from 0 (which in this case implied no fluorosis or excluded from count) to 240 which reflects the most severe dental fluorosis recoded. The overall mean TFI for the six regions together was 3.39. This reflects moderate towards severe fluorosis. The mean TFI score did not vary by age or sex.

Table 8-16 Mean TFI for Different Tooth Types

Tooth type	Mean TFI score
Incisors	2.40
Canines	3.23
Premolars	3.87
1st Molars	4.09
2nd molars	4.14

Arusha region had the highest mean TFI score (4.29) followed by Shinyanga (3.52), Singida (3.36), Manyara (3.30), Tabora (2.7) and Dodoma (1.74). Analysis by district revealed that Arumeru district had the highest mean TFI score (4.84) followed by Manyoni (4.24), and Meatu (4.07). Minimum levels were recoded in Singida Urban district (1.40) and Kondoa (1.49).

Table 8-17 Mean TFI of Each Region

Region	No. of Children	Avarage TFI
Arusha	150	4.29
Shinyanga	1,245	3.52
Singida	941	3.36
Manyara	330	3.30
Tabora	155	2.70
Dodoma	91	1.74
Total	**2,912**	**3.4**

TFI score analysis by village revealed that Kolandoto village in Shinyanga had the highest mean TFI score of 5.17, followed by Olkungwado village in Arusha with a score of 4.90, and Lemong'o (4.78). The lowest mean TFI score (0.41) was recored at Iyumbu village in Singida region.

(5) Dental Fluorosis and Fluoride Levels in Water and Magadi Samples

Pearson correlation "r" indicated non significant association between dental fluorosis and water fluoride levels ('r"= 0.03, p = 0.112) and for magadi fluoride levels "r"= 0.06, p = 0.07). Controlling for altitude (that is known to influence the propensity of fluoride to cause dental fluorosis), the association between dental fluorosis and water fluoride levels turned out to be "r" = -0.11) and for

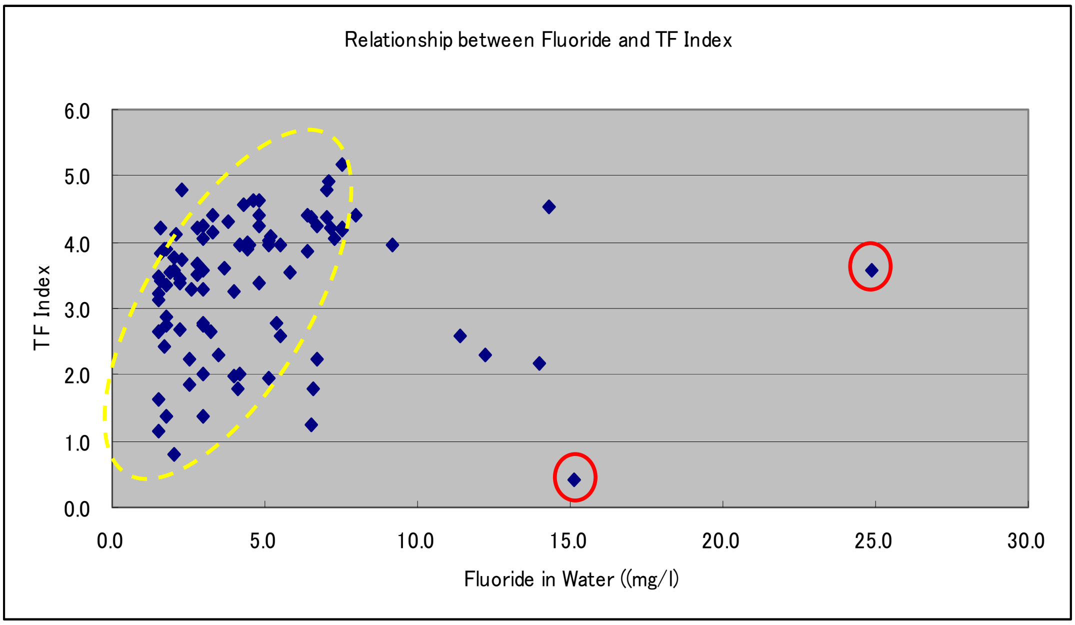


Figure 8-12 Relationship between Fluoride and TF Index

magadi ("r = -0.16) indicating no linear association between severity of dental fluorosis and fluoride levels in drinking water and magadi. Categorising dental fluorosis and water fluoride levels cross-tabulations revealed significant differences (X^2 = 66.03, p= 0.000) in the proportions of individuals with different TFI scores in the different categories of water fluoride levels. However, the differences did not display the expected trend of dental fluorosis severity and water fluoride levels (Figure 8-12). Although this survey was not designed to prove the correlation between fluoride in the water and dental fluorosis, the scatter diagram above which correlates the two variables shows a rough relationship between the two. The ideal condition would be a TFI of 0 with Fluoride in the water of 1.0mg/L. However, the above figure shows that in this study no one had TFI of 0 and no water sample had less than 1.5mgF^-/L. As a result, more than half of study participants had TFI of more than 3. Abnormal findings were observed and among the reasons for such results have been explained above. Obviously, the use of magadi with different fluoride level and use of various sources of water complicates the correlation.

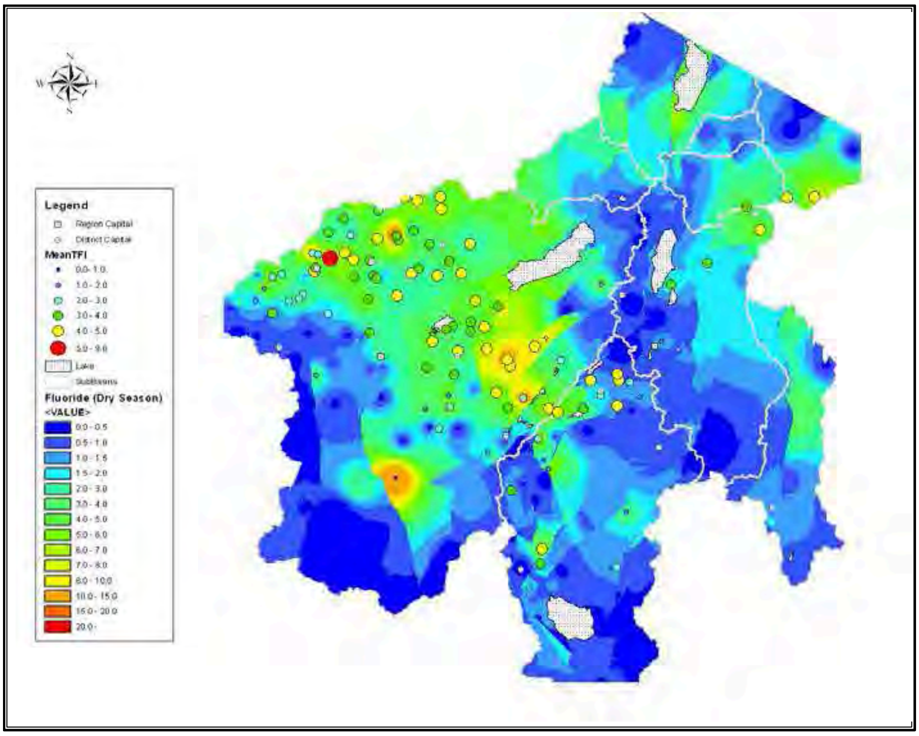


Figure 8-13 Distribution of Mean TFI by Dental Survey Examination and Fluoride Levels in Water

Exploring the data further, it was revealed that Kolandoto village in Shinyanga for example, had the highest mean TFI score of 5.17 but its fluoride levels in drinking water was 7.50 mgF^-/L and, on the other hand Gula village in Shinyanga that had the highest fluoride level (24.9 mgF^-/L) its mean TFI score was 3.57 and Iyumbu village in Singida had the lowest mean TFI score of 0.41, amazingly, its fluoride level in drinking water was as high as 15.1 mgF^-/L. It should be recalled from section 4.2 above that only 21% of the children reported to have been using the water sources that were analysed by the quality survey team as their regular source. Therefore correlation coefficients between TFI scores and levels of fluoride in water provided, revealed a very weak non significant association. On the other hand, questionnaire findings revealed that children of the same village use different regular water sources. For example, it was established that 16 villages had two regular water sources each used by more than 40% of the participants.

(6) Awareness on Dental Fluorosis

Out of all the children who were interviewed and willing to respond, 94.3% acknowledged that people in their community had fluorotic teeth. The small proportion that reported not to have seen anyone with fluorotic teeth in their village, were most likely those who mistaken brown teeth for dirty teeth. They declined to expose their community to be known for poor oral hygiene. As indicated in the open-ended question exploring the causes of dental fluorosis a number of children believed dental fluorosis was caused by failure to brush teeth. Sixty eight percent reported to be aware of the fact that their teeth were fluorotic and about the same proportion reported that their family members also had fluorotic teeth (Table 8-18).

Table 8-18 Knowledge and Awareness Related to Dental Fluorosis

Knowledge and awareness questions	YES		NO		Total
	n	%	n	%	n
Seen fluorotic teeth in village	2747	94.6	155	5.34	2902
Own teeth are fluorotic	1993	68.67	909	31.33	2902
Family member have fluorotic teeth	1955	67.41	945	32.59	2900
Fluoride in water cause fluorosis	1082	37.16	1829	62.84	2911
Fluoride in magadi cause fluorosis	703	24.14	2208	75.86	2911
Fluorosis is inherited	164	5.63	2746	94.37	2910
Fluorosis is caused by tooth decay	213	7.31	2698	92.69	2911
Stop using high fluoride magadi prevents fluorosis	742	25.49	2169	74.51	2911
Stop using high fluoride water prevents fluorosis	956	32.84	1955	67.16	2911

(7) Perceptions on Fluorosis

Fifty nine percent reported that fluorotic teeth make them feel shy. About two thirds (66.2%) felt frustrated about their fluorotic teeth, and 48.4 % claimed to feel inferior because of fluorotic teeth. A follow-up question to check whether fluorotic teeth impinged their self esteem revealed that 47.6% were affected. And (39.4%) reported that their self confidence was affected by dental Fluorosis. About two thirds (59.6%) indicated that they were not satisfied with their physical appearance and that they considered themselves as being less attractive (62.0%)

As regards perception on what people with fluorotic teeth feel, 59.6 % of participants were of the opinion that people with fluorotic teeth feel embarrassed to interact with people. It can be noted that whether questions were directed to individuals or indirectly through other people the psychosocial impact of fluorosis is felt by about two thirds of the people.

When the seven, five-point scaled questions measuring the psychosocial impact of fluorosis were additively combined, a summative index for perception was obtained with scores ranging from 7-35, (mean = 22.3). Nearly half of the children scored more than 22. This mean score indicates that these children were inclined towards high scores of the scale which expresses their dissatisfaction with brown teeth. Irrespective of age and sex the children had similar perceptions on brown teeth (mean scores were 22.2 for males and 22.4 for females; mean scores for ≤14 years was 22.4 and for 15 years or more years was 22.2).

(8) Knowledge on Causes of Dental Fluorosis

Only 37.2% of the children knew that water with high levels of fluorides would lead to dental fluorosis and even a much lower proportion (24.1%) knew that high fluoride magadi would cause dental fluorosis. When asked in a reversed order a similar proportion of children could tell that stop using water (32.8%) and magadi (25.5%) with high fluoride levels would prevent dental fluorosis. A small proportion but worth noting is the 5.6% who believed that dental fluorosis is inherited from parents and some (7.3%) thought dental fluorosis is caused by tooth decay. On further probing using an open ended question, it appears there is a common understanding that poor oral hygiene causes dental fluorosis, while some also believed sugar consumption causes browning of teeth. The overall view points to the fact that a large proportion did not know what causes dental fluorosis. When asked about their motivation to participate in a project that will provide safe water with low fluoride levels only one third were motivated to participate. The reason for low motivation was scepticism of whether or not fluoride in water really causes dental fluorosis (Table 8-18).

(9) Water source and storage

Questionnaire findings as reported by indicated that water was reported to be obtained from the following regular sources; shallow wells (48%), tape water mainly from deep wells 21.5%, permanent and temporary rivers (20.9%), spring (3.9%), dame/lake (3.9%), unknown sources 1.6% and rain water 0.1%. However, it was only 60.6% who obtained their water from the same water source throughout the year. When the regular sources were out of supply, their alternative sources included shallow wells, rivers, spring, tape-water mainly from deep wells, dam or lake, and rain water. Almost all (95.9%) store their water before use. The main storage vessels included clay pots (59.9%), plastic containers (37.0%), metal containers (1.5%) and a small proportion stored in calash and other containers.

8.3.4 Conclusions

The study has remarkably showed that the prevalence and severity of dental fluorosis is very high in IDB area due to consumption of high levels of fluoride. This is explained by the fact that, no source of water as analysed had normal readings of fluoride levels as per WHO standards. In addition, the consumption of magadi as food additive partly explains the high prevalence and severity of dental fluorosis in IDB area. Nevertheless, the association between dental fluorosis and fluoride concentration in water could not be ascertained in this study because of the complexity involved in associating the two variables that are complicated with other factors such as ingestion of magadi with high fluoride contents. The children expressed their dissatisfaction with brown teeth, feel shy, frustrated, reduced self-esteem and self-confidence. The overall view points to the fact that a large proportion of children did not know what causes dental fluorosis. Shallow well was reported by children to be the most frequently used water source.

Fifty percent of the water samples were from sources that had fluoride levels higher than or equal to 4.0 mg/L and none of the sampled water had normal fluoride concentration. This signifies that most of shallow water in IDB region also contains excess level of fluoride. Ingestion of magadi, which also contains high levels of fluoride worsen the situation.

8.3.5 Recommendations

1. The high prevalence and severe dental fluorosis definitely calls for an intervention. As globally known dental fluorosis is due to frequent ingestion of high amount of fluorides in water and food. Although the findings of this survey did not reveal linear association between fluorosis and fluoride, its still strongly recommended that efforts are made to get alternative water sources with optimum fluoride levels.
2. The psychosocial impact of dental fluorosis has been well demonstrated in this study group. It sounds logical to assume that any measure directed towards solving the problem of dental fluorosis will be highly appreciated. Nevertheless due to poor knowledge on the causes of dental fluorosis there was scepticism on whether alternative water source will prevent dental fluorosis. Therefore the community must be educated about the causes of dental fluorosis prior to the commencement of the intervention
3. Despite that the sources of water from where samples for fluoride analysis were collected could not match with the water sources that are used as reported by the children, the level of fluorosis in itself still confirms the exposure to excessive fluoride. Therefore a search for optimum fluoride water sources should continue unabated.

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