Report No. 01/93
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GROUNDWATER STUDY OF ADDIS ABABA AREA

July 2001
Addis Ababa

Contents

Groundwater of Addis Ababa area

1. General

Addis Ababa is found in the Akaki River catchment. The northern boundary of the town is Entoto Mountain Range. The volcanic mountains; Mt. Furi located southwest of the town and Mt. Yerer located south-east of the town are high massive volcanic centers rising to elevations of 2,839 and 3,100 m, respectively. These two peaks heights form the western and eastern drainage divides of Akaki River respectively.

The morphology of the Addis Ababa area is complex. Entoto Ridge, which constitutes the northern boundary of Addis Ababa, has ragged topography characterized by steep slopes rapids and water falls. Towards the south, the morphology changes to quite gentle slopes though there are some hilly features.

The long term mean annual rainfall observed at Addis Ababa Observatory is 1254mm. The maximum temperature varies on average between 20° C in the wet season and 25° C in dry season, while the variation of minimum temperature falls in the range of 7° C to 12° C throughout the year. Wind speed is generally moderate in the area, taking average values in the range of 0.5 to 0.9m/s. Average daily sunshine hours as high as 9.5 hours are observed in November and December, and this figure falls to 3 hours or less in July and August. Monthly pan evaporation records, obtained from documents of previous studies, reveal that the average monthly pan evaporation during the dry season (November) at Addis Ababa Observatory is about 180 mm and this value falls to about 75 mm in wet season (July).

The main objective of the groundwater study of Addis Ababa area is aimed to supply information needed for the planning of wastewater facilities and EIA's. The groundwater study mainly focuses on;

a) Preparation of maps (scale 1:50,000) of Addis Ababa area

- Indicative subsurface infiltration map
- Groundwater depth contour map
- Indicative groundwater pollution vulnerability map

b) Indicative extent of the Akaki well field protection zones, impact of waste water treatment plants/sludge disposal sites on the groundwater especially Akaki well field and design of groundwater monitoring scheme at wastewater treatment /sludge disposal sites.

It should be noted that the above maps are prepared exclusively from secondary data (archive data and from previous maps and reports) without generating any primary data. The analysis of impact of wastewater treatment plants/sludge disposal sites on Akaki well field and on the groundwater on sites is based on maps prepared scale 1:50,000(sub-surface infiltration map, groundwater depth, potentiometer map, water quality data of 1993 and 2000 bore holes inventories carried out by AAWSA).

2. Methods of the study

The preparation of the groundwater study of Addis Ababa is exclusively carried out by reviewing previous studies, maps and archives data. In the course of the study, the different reports maps and archives data were studied, reviewed and used for the preparation of the present report. Distribution of boreholes data used for the preparation of different maps is given in figures a and b.

3. Geomorphology and unconsolidated sedimentary deposits

The subsurface infiltration condition of Addis Ababa area is mainly governed by the thickness and hydraulic conductivity of the unconsolidated sediments overlying on the weathered and fractured volcanic rocks. The weathered and fractured volcanic rocks are relatively porous with relative high infiltration condition. The genetics and thickness of the unconsolidated deposits varies as a function of topography and geomorphology. Genetically they are broadly classified into three groups (Teshayu K & H/Mariam, 1990). They are alluvial, residual and lacustrine clay deposits.

The alluvial deposit mainly composed of clay is found along Akaki River and its tributaries and its thickness and clay proportion increase along the river flow direction or in the southern direction of Addis Ababa around Aba Samuel.

The high elevation, ridges and steep sloped areas of the town are covered by thin layer of residual clay soils while watershed divide and plain areas of the town (central and upper part of the town) are covered by thick residual clay soils. The southern part of the town (Akaki and Aba Samuel area) is covered dominantly with very thick lacustrine deposits. The lacustrine deposits are black cotton of highly plastic clays thickness up to 40 meters.

Hydraulic conductivity of the different genetic unconsolidated deposits is estimated based on grain size distribution tests conducted by BCEOM/GKW 1993 on alluvial and residual deposits at different places of Addis Ababa and literature review for black cotton soils of lacustrine deposits. The grain size analysis at different places (UDPO market, Bole Air port, Kotebe, Filowuha, Jan Meda, Kolfe Market place, Teklehaymanot, Gola Michael, Kera and Kality treatment) their grain size distribution by weight is given in table 1.

Table1 Variation of Grain size distribution by weight in %

Description	Sand (%)	Silt (%)	Clay (%)	Description
Min	2 (sandy silt clay)	20 (sandy silt clay)	21(clay sand silt)	
Max	34 (clay sand silt)	55 (sandy clay silt)	73 (sandy silt clay)	
Avg.	15.72	35.33	48.95	Sand silty clay

The hydraulic conductivity is estimated for the average condition of sand silty clay of residual and alluvial deposits is about 0.0017 m/day. The clay sand silt and sandy clay silt deposits are alluvial deposits along Akaki river and its tributaries. For the black cotton soils of lacustrine deposits is estimated about 0.000086m/day.

Based on the available secondary data (well log data, Suereca 1993, Akaki groundwater modeling BCEOM/Suereca 2000) indicative subsurface infiltration map scale 1:50,000 is prepared (fig.1). From the map it can be clearly seen that the plain part of the town (Bisrate Gebriel, Kaliti and Akaki areas) is covered by thick clay more than six meters of very low hydraulic conductivity and the large part of the town is covered by thin clay deposit less than three meters.

Fig.1 Indicative subsurface infiltration map scale 1:50,000 is prepared (fig.1)

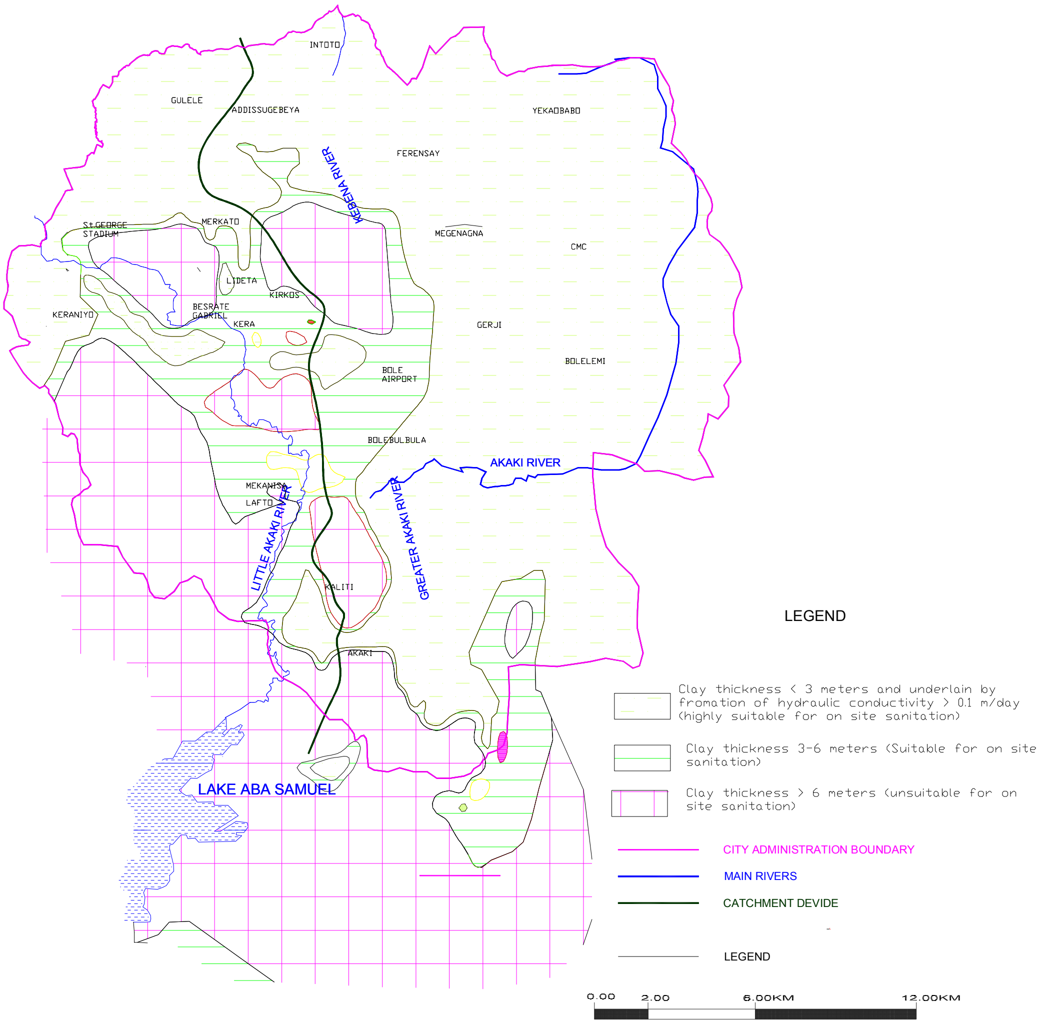


Fig. 1 Indicative Sub surface Inflitration Map of Addis Ababa Area

4. Geology

According to the studies conducted by different geologists on the city of Addis Ababa area (Kebede Tsehayu & Tadesse Hailemariam, 1990, Seureca, 1991, Morton and al, 1979, Antonio Vernier & Tesfaye Chernet, 1985, Gasparon and al, 1993 and BCEOM/Suereca 2000), the following rocks are exposed generally from the north to the south (fig. 2). They are:

- Trachytes, rhyolites , basalts and pyrocalstics of Entoto Mountain and northern and northeast Addis Ababa.
- Basalts of the central and southern Addis Ababa known as Addis Ababa Basalt;
- Ignimbrites of the eastern (Bole area) and central Addis Ababa (Ledeta area);
- Trachy-basalts, trachyte, ignimbrite and tuff forming the volcanic mountains of Wechecha, Furi and Yerer;
- Basaltic lava, spatter and cinder cones and maars of Akaki and
- Lacustrine deposits, Alluvial and residual soils: Lacustrine soils occur around Bole, Lideta, Mekanisa, between Abasamuel Lake, Akaki town and small Akaki River and their thickness of this deposit varies between 5m and 50m.

Since Addis Ababa is located at the edge of the Ethiopian Rift, there are a number of fault systems having a general trend of the rift system (NE - SW) and some faults and lineaments oriented E-W, N-W and NE - SE. The density of faults and lineaments increases to the southeast of the town towards the rift valley.

5. Hydrogeology

5.1 Hydrogeological setting

Addis Ababa city area is found at the edge of the main Ethiopian rift valley. The dominant geological formation found in the city area is volcanic rocks (ignimbrites, ryholites, basalts, scoria, etc). Generally, from north south the geological formation changes from trachytes and ryholites at the north to basalts at the center to basaltic lava and cinder cones to the south.

The aquifers of northern and central part of Addis Ababa city and in the mountain area are largely due to weathered and fractured volcanic rock with minor sediments deposited between different series of lava flows. The aquifers at the southern part of the city (Akaki well field) are mainly young volcanic rocks of lava flow and tectonic fractures. In general, the aquifers are complex and highly variable. The thickness of the aquifers is not yet determined.

Fig.2 Geological map of Akaki river basin (BCEOM 2000)

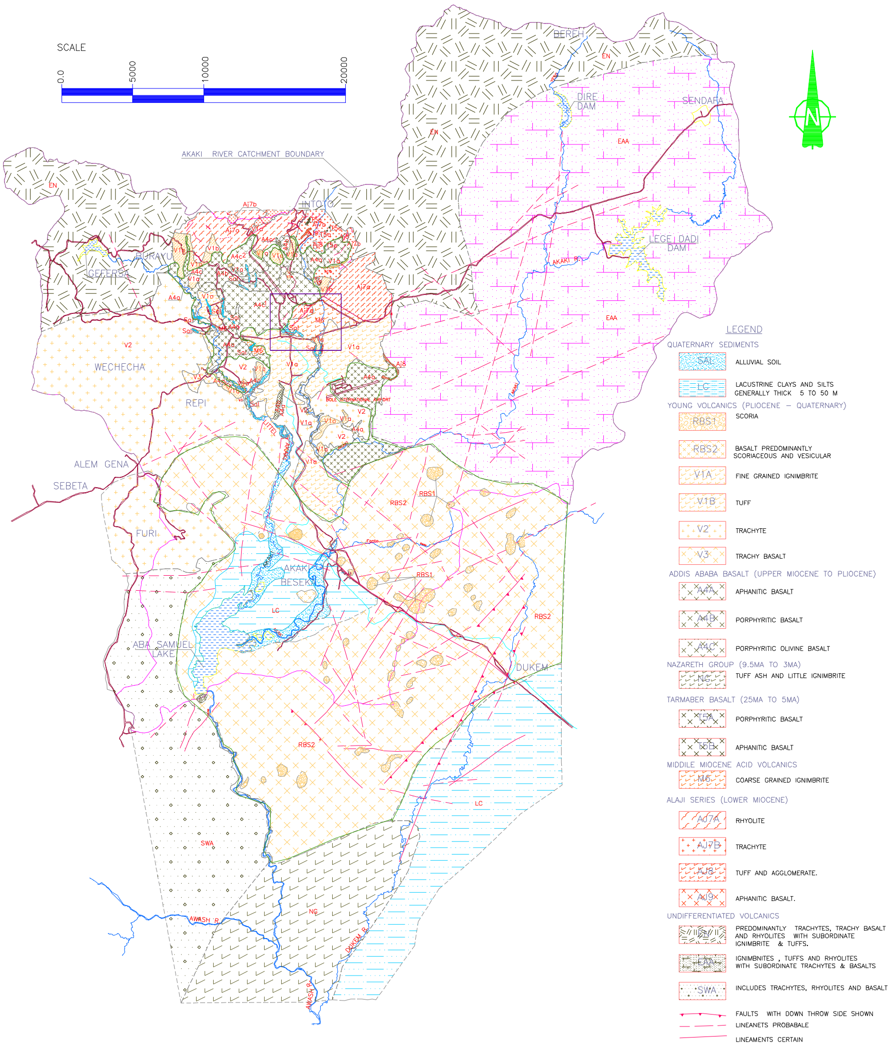


Fig.2 Geological Map of Akaki River catchment (Adapted from BCEOM/Sureca 2000)

Scale 1:50,000

The aquifers of Addis Ababa area can be broadly characterized as follows;

- The annual groundwater recharge is estimated to be about 51-100mm for Akaki catchment.
- At Akaki well field (south of the city), the groundwater level is found about 20 to 30 meters down from the bottom bed of Akaki River.
- The general groundwater flows direction within the city is from north to south.
- Transmissivity, bore holes yield, depth of groundwater and total dissolved solids increases from north to south direction. There are exceptions at some places of the town, which have high yield and total dissolved solids caused by intensive fracturing and thermal effect respectively.
- Analysis of bore holes log data revealed that the central part of the city elongated in the north-south direction (Filwoha, Llideta, Kality, etc. areas) exhibits confined groundwater condition. Some of bore holes data at the confined groundwater area are given in table 2. The confining heads generally decreases to all direction from the centre of the city.

Table 2 Some of the confined groundwater places of Addis Ababa

WELL LOCATION NAME	CO-ORDINATES, M UTM east	UTM north	DEPTH TO SWL (M)	WATER STRIKED	CONFINING HEAD, M
St. Poulos Hospital	469900	1001000	7.00	51	44.00
West German Embassy	475600	998900	20.00	72	52.00
Grand Palace-1	474200	997400	6.00	54	48.00
Technical School	471700	995900	16.00	65	49.00
Ministry of Mines	471800	995500	11.00	59	48.00
Defence Inustry-1	471300	995400	Artesian	90	90.00
Defence Inustry-2	471300	995600	Artesian	90	90.00
Cigarette Factory	471300	994800	14.00	67	53.00
SEDE(plant-A) - 1	471700	995100	7.40	52	44.60
Old Airport (Army)	469300	995500	16.00	92	76.00
Hana Mariam-2	471700	986600	26.10	56	29.90
Albergo Italia	471300	996200	6.00	43	37.00
St. George's Cathedral	472500	998700	14.00	42	28.00
Private Well	472400	998500	5.00	39	34.00
Ministry of Public Works Office	472500	996600	7.00	26	19.00
Water III Testwell-B6	470800	982900	artesian	23	23.00

Source: Water Supply Master Plan of Addis Ababa Stage III, Groundwater, Suereca 1993

Fig.3 Groundwater depth

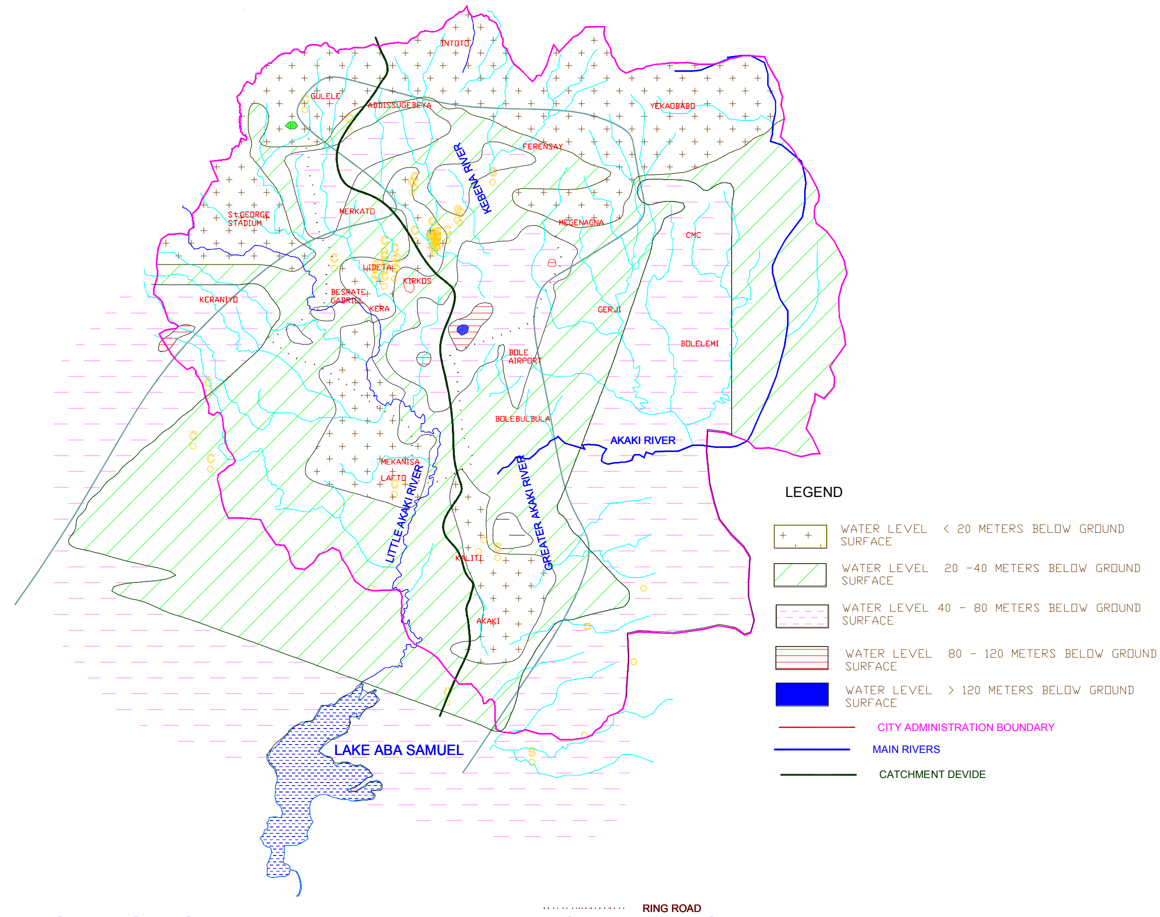


FIG.3 GROUND WATER DEPTH OF ADDIS ABABA AREA

(Based on bore holes inventory data of AAWSA April-May 2000)

5.3 Groundwater depth

The groundwater depth map of Addis Ababa area is prepared from April/May 2000 boreholes inventory data (fig.3). The map shows shallow ground water depth at the central and the northern part of the town. As discussed earlier, the central part of the town shows confined groundwater conditions. Especially at some places of Filwoha, Lideta and Kality areas exhibits artesian groundwater conditions. The confinement at the central part of the town varies from 23 to more than 100 meters. The confinement is maximum along elongated strip north-south direction (Filwoha, Lideta, Mekanisa, Lafto, Kailty) and the confinement decreases both in the eastern and western direction from this elongated strip. Most of the shallow groundwater area at the north of the town is unconfined.

Large proportion of the central part of the town is under confined groundwater condition with groundwater depth varying from 0 to 40 meters. The depth of the groundwater in general, increases in the south direction. There are also deep groundwater areas more than 120 meters depending the topography of the area.

5.4 Groundwater flow

The groundwater flow within the town is variable with a general direction in north south direction. There are groundwater divides, which have a north south elongation. At Akaki well field area (south of Addis Ababa) the groundwater flow concentrates (fig.4).

5.5 Groundwater quality

As indicators of the groundwater quality of Addis Ababa city area total dissolved solids (TDS), Chloride and Nitrates are considered. Chloride and nitrate values of the groundwater in the model area are good indicators of potential contamination of groundwater. Increase in chloride concentration is a result of pit latrines, waste disposals and from the city water supply, which uses chloride for water treatment. High nitrate is mainly contamination from waste disposals.

Analyses of the 1993 and 2000 water quality analysis of AAWSA (BCEOM/Suereca 2000 and Water quality data of April/May 2000 from Surface and groundwater division of AAWSA) show the following results:

- High nitrates greater than 50mg/l is observed (fig.5) around Merekato area where the population density is maximum and at Akaki town relatively high nitrate is observed (>20mg/l).

- Relatively high chloride (~200mg/l) is observed around Merkato area where the population density is maximum (fig.6)

- High TDS areas are observed at the central part greater than 1000mg/l (Filowuha area) and west of the city. These localized high TDS areas have northeast southwest direction following the main rift valley direction. The high TDS areas are mainly due to the thermal water effects (fig.7).

5.6 Groundwater vulnerability to pollution

Superimposing the groundwater condition, groundwater depth, lithological composition and present status of pollution of Nitrates and Chlorides indicate the following conditions.

The high nitrate and chloride observed at Merkato Area corresponds to the maximum population density within Addis Ababa. However, from the point of the groundwater condition of the area lead that the contamination of the groundwater at Merkato and to a lesser extent at Akaki may be most probably due to:

a. Poor well construction of boreholes and improperly abandoned wells and

b. Septic tanks and laterine pits closely located to wells that provide contaminate pathway as a short and through the unsaturated zone

However, taking into consideration of the groundwater condition (confined and unconfined), groundwater depth, thickness of unconsolidated deposit an Indicative Groundwater vulnerability to pollution map of Addis Ababa area is prepared (Fig.8).

The groundwater Addis Ababa which is unconfined and groundwater depth is less than 80 meters is considered highly vulnerable to many pollutant except those highly absorbed and or readily transformed. The main reason to consider it highly vulnerable is that the aquifers are fractured and weathered volcanic rocks, with a probability to transfer polluted water through the fractured unsaturated zones.

The semi-confined aquifers of Addis Ababa area are considered as low vulnerability area due to the existence of Semi-impermeable strata between the groundwater level and source of contaminant, which prolongs the travel time to reach the groundwater.

The confined zone of the groundwater of Addis Ababa area is considered negligible vulnerability to pollution due to the high confinement of the groundwater with impermeable strata.

Fig.4

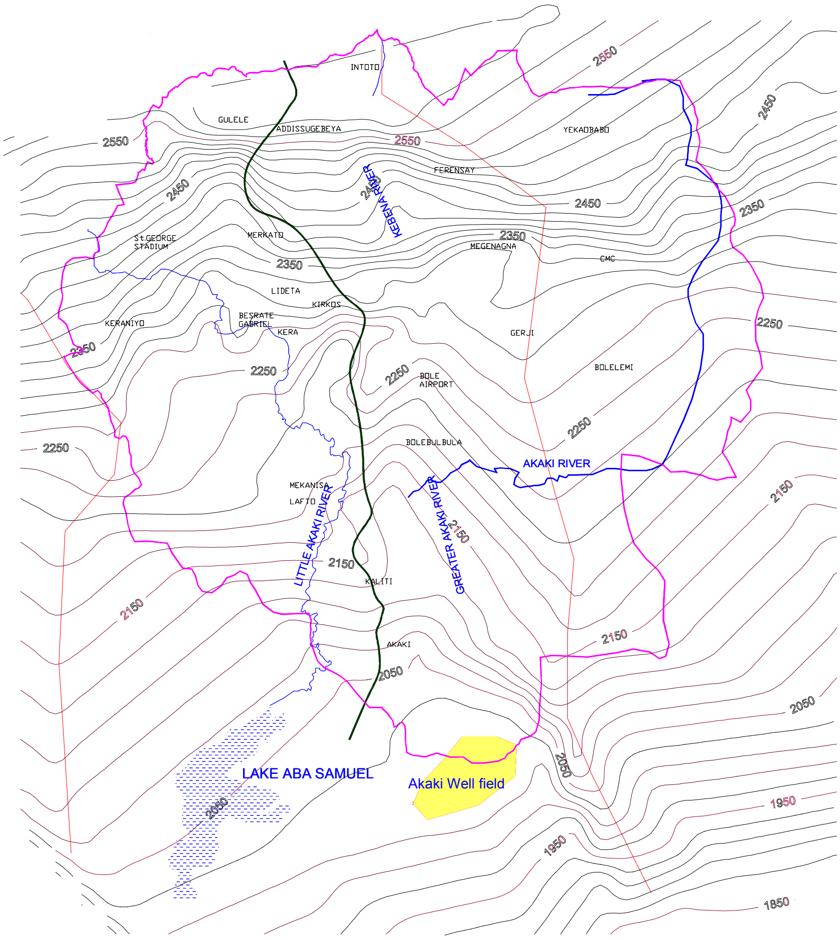


Fig. 4 Potentiometric Map of Addis Ababa Area

LEGEND

Akaki wellfield
water level (masl), m
Groundwater divide
CITY ADMINISTRATION BOUNDARY
MAIN RIVERS
CATCHMENT DEVIDE

Fig.5

FIG. 5 NITRATES DISTRIBUTION AT ADDIS ABABA AREA (NO3 mg/l)

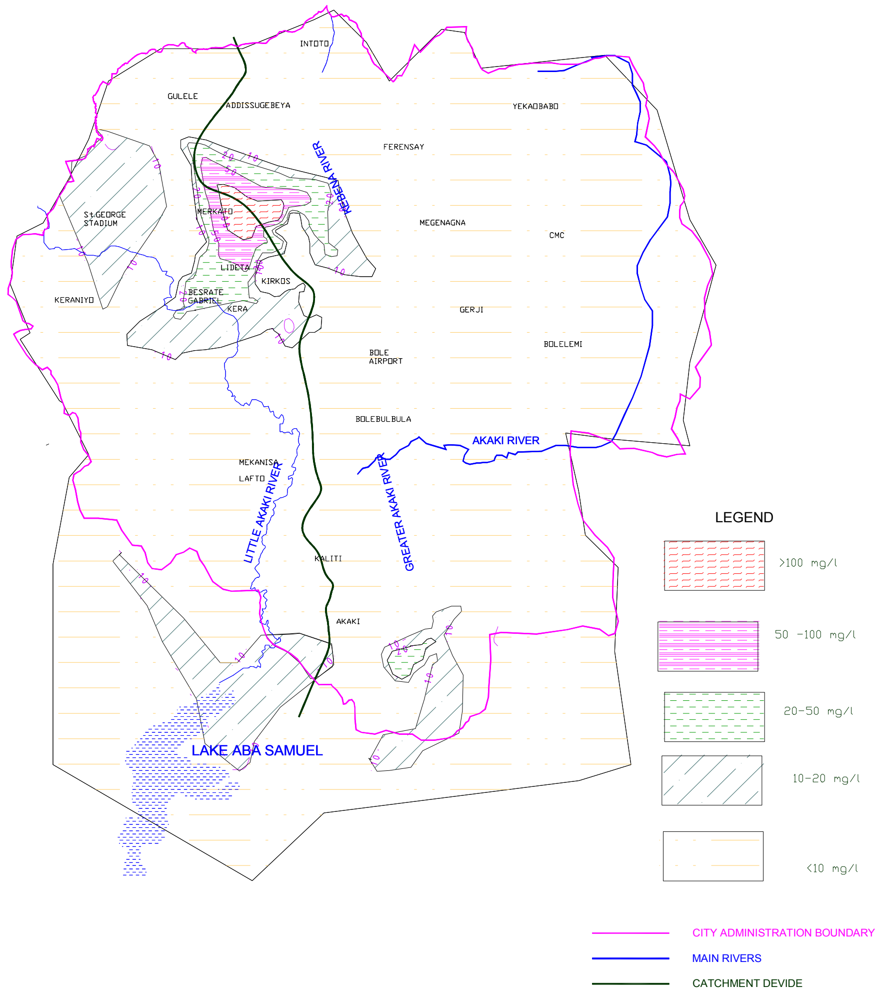


Fig.6

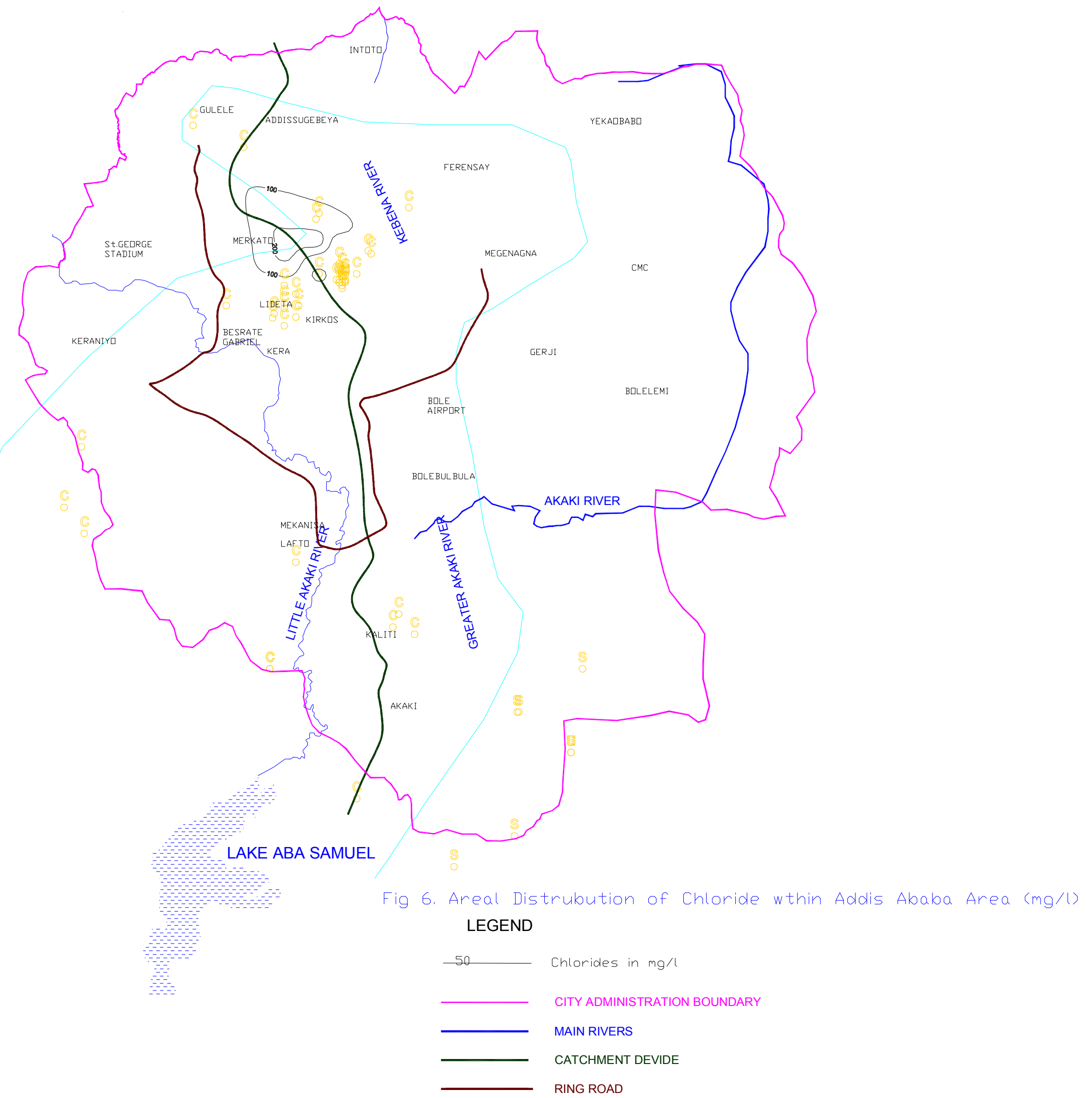


Fig 6. Areal Distrubution of Chloride wthin Addis Ababa Area (mg/l)

Fig.7

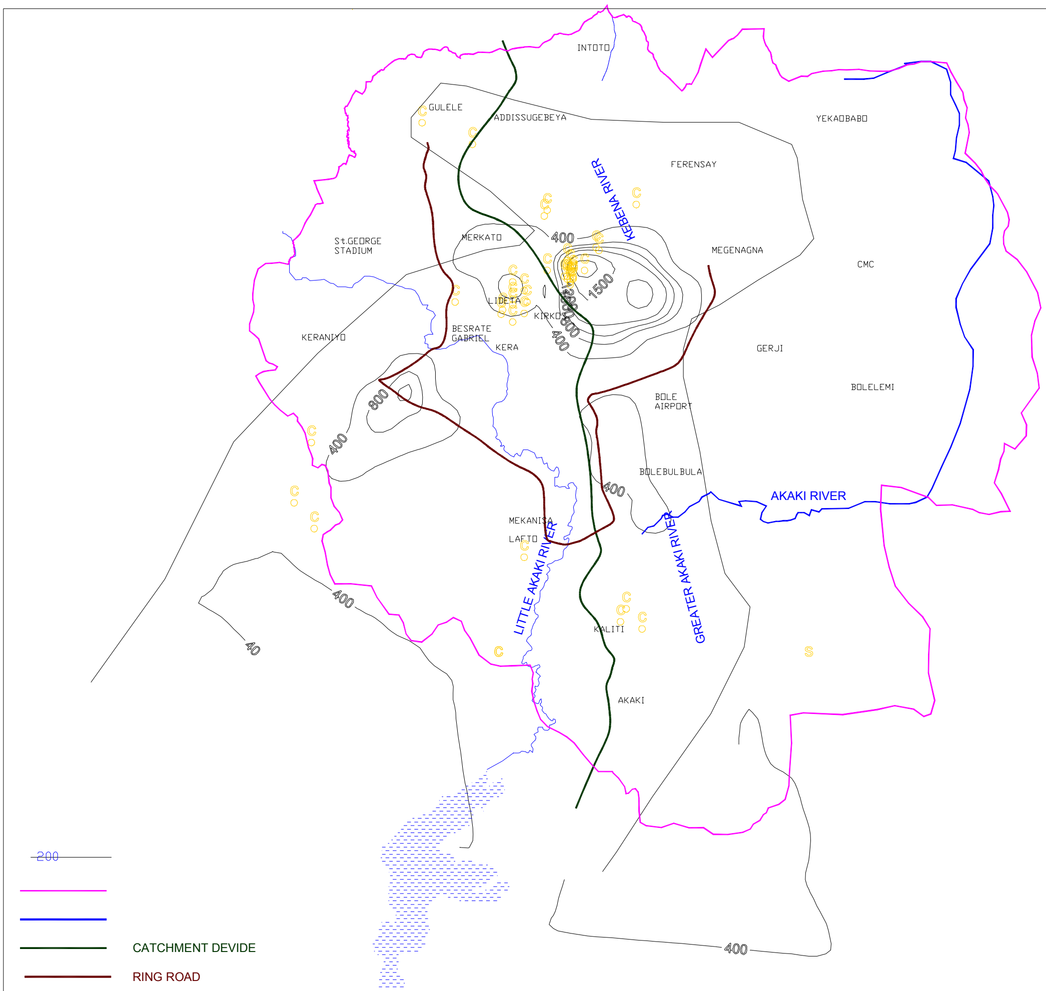


Fig. 7 Areal Distribution of total dissilved solids (TDS) within Addis Ababa area (mg/l)

Fig.8

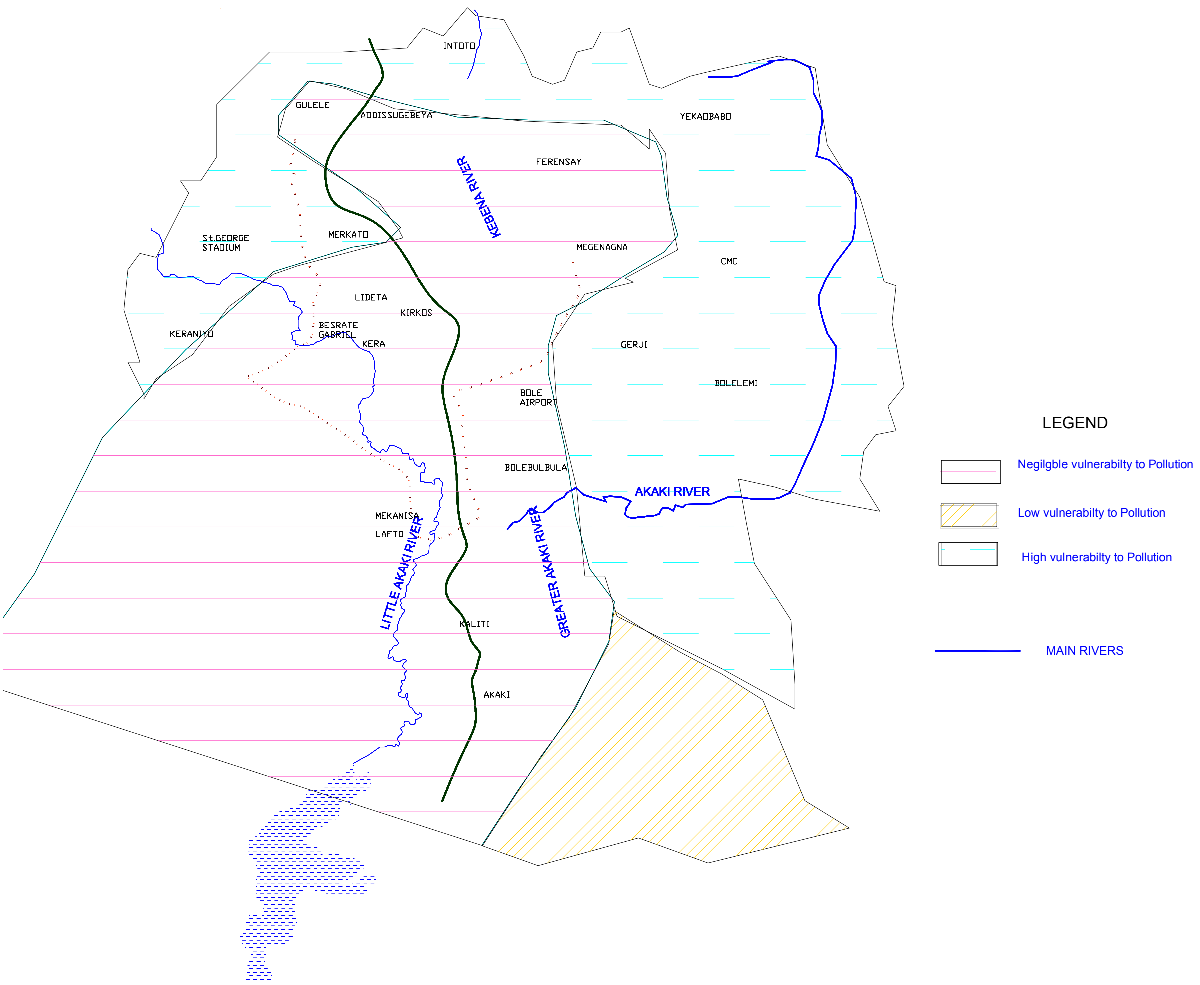


Fig. 8 Groundwater Vulnerability to Pollution of Addis Ababa area

6. Akaki Well Field

6.1 General

Lithological log of boreholes at Akaki well field shows that the underlying volcanic rocks are overlain by thick alluvial lacustrine clay deposit with a number of clay layers interbedded between the volcanic rocks (Scoria, Scoriacious basalt, and basalts).

In general, the aquifers of the well field are interbedded basaltic lava flow and scoria, semi-confined of multiple layers with a groundwater depth varying from 40 to 70 meters deep. The groundwater flow is nearly north to South. The transmissivity calculated from 14 boreholes drilled on the well field varied from 1833 m^2/day to 105, 408 m^2/day with average value of 27636 m^2/day.

The area surrounding the well field in all directions have low transmissivity values compared to the well field (fig.9).

Akaki river, which crosses the well field is not hydraulically interconnected with the ground water i.e. the water table in the well field is more than 30m below the Akaki river bed.

6.2 Present and Future Development of the Well field

At present, the well field is the main water supply Source for Akaki Town. The ground water modelling carried out on the well field indicated that about 30,000 m^3/day can be abstracted from the well field for 20 years (BCEOM/Suereca, 2001).

However, the hydrogeological condition of the well field indicates a possibility to abstract more water from the well field by carrying out appropriate distribution of wells & well design, deeping of the boreholes and increasing the areal extension of the well field in the southern direction. Further study and investigation is in progress at present by BCEOM/Suereca in association with Tropics Consulting firm to evaluate the possibility of increasing the groundwater exploitation from the well field.

6.3 Vulnerability to Pollution

As stated earlier, preliminary studies conducted on the area and boreholes logs data on the well field and adjacent areas show that;

a) Akaki river & Aba Samuel (highly contaminated surface waters) and the groundwater are hydraulically not inter connected.

b) Thick clay deposit overlays the volcanic aquifer of the well field.

c) The volcanic aquifers at depth are interbedded by clay layers

Fig.9

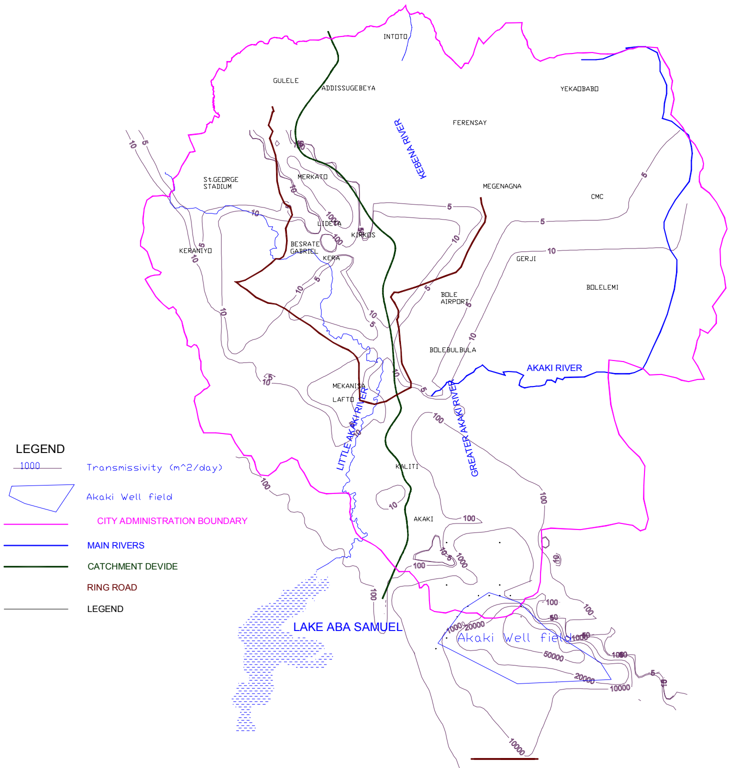


Fig. 9 Areal Distribution of Transmissivity (m^2/day) Addis Ababa area

d) The groundwater depth varies from 40-70 meters deep indicating that the un-saturated thickness is more than 40 meters.

The clay deposit at the well field vertical varies from black cotton clay to sandy clay and there are not primary data for the permeability of the clay deposits of the area. Here is generally assumed low permeability clay deposits. For low permeability clays, the vertical permeability varies from 10^{-5}- 10^{-7} m/day and specific yield of 0.01.

The natural protection of the well field is mainly a function of the thickness and permeability of the clay deposit overlying the volcanic aquifer. The time required a contaminated water to penetrate a known thickness of clay deposit can be calculated by the following formula.

$$t = \frac{SH}{k} \quad ...... (1)$$

where, t - travel time to penetrate
H -meters of clay deposit, days

H - Thickness of clay deposit, m
K - permeability of clay (m/day)
S - Specific yield

Table 3 Travel Time of contaminate (Day)

N/N	THICKNESS OF CLAY, m	SPECIFIC YIELD (S)	PERMEABILITY (M/DAY)	TRAVEL TIME, DAYS
1.	20	0.01	10^{-3}-10^{-5}	2,000 - 20,000
2	10	0.01	10^{-3}-10^{-5}	1,000 - 10,000
3	5	0.01	10^{-3}-10^{-5}	500 - 5000
4	<3	0.01	10^{-3}-10^{-5}	300 - 3000

Therefore, areas with travel time greater than or equal to 10,000 days can be considered as highly protected area groundwater zone (third zone protection zones).

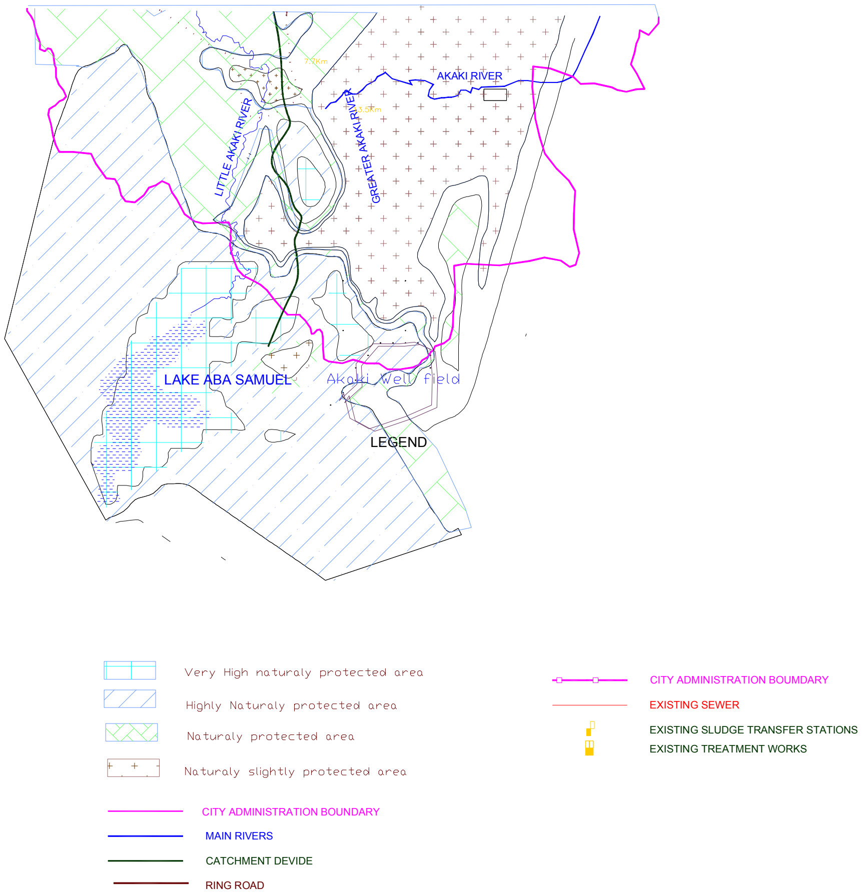
The lateral extent of the clay thickness on the well field and adjacent areas is given in fig 10.

6.4 Well Filed Protection Zones

To conserve the natural composition and quality of Akaki well field it is important to protect it from contaminates that may reach to the exploited water bearing layers. Protection of the well field from contamination can be realized:

Fig.10

Fig.10 Natural Protection Condition to Pollution of the Groundwater at Addis Ababa area



a) By providing protection zones around the well field, if to carry out activities within the protection zones.

b) When there are activities, which may contaminates the well field within the protection zone, it should be provided with special structures and plants that would curtail the contamination.

The sizes of the protection zones are based upon criteria of time travel to reach the aquifer.

The first zone (Inner Zone) is to protect deliberate and/or accidental contamination of the well field. In the Akaki well field the distance between the boreholes is about 500 meters. Therefore, it is not possible to provide one inner protection zone for the whole well field. As already constructed out fencing of each boreholes within 5-10 meters radius and assigning a guard would be sufficient.

Zone 2 - Flow protection zone to protect the aquifer from biological and chemical contamination. The radius of the protection zone is determined based on a travel time of 1000 days.

Zone 3 - Outer Source Protection zones: The third zone is to protect the well field from chemical contamination especially stable contaminants which doesn't change in the groundwater their composition and concentration as a result of physical and chemical interaction with the groundwater and rocks. Travel time of 10,000 days is considered for the third protection zone. Based on the hydrogeological condition of the second and third protection zones are calculated by Analytical method.

Analytical Calculation of Protection zones: Akaki well field is semi confined aquifer thickness, about 100 meters, flow direction north -south direction with gradient of about 0.001. The transmissivity of the aquifer varies from 1823 m^2/day to 105,000 m^2/day with an average of 26,376 m^2/day.

There are about 20 boreholes in the well field are distributed within a distance of 500 meter a part each other. The total area of the well field is about 500,000 m^2. The boreholes in the well field can be approximately changed into one equivalent boreholes which will has the total discharge of the wells and radius (r_{eq}).

$$r_{eq} \approx 0.47 \sqrt{\frac{A}{II}} \qquad \ldots\ldots\ldots\ldots\ldots(2)$$

$$r_{eq} \approx 0.47 \sqrt{\frac{5{,}000{,}000}{II}}$$

$$r_{eq} \approx 1050 \text{ meters}$$

For the third protection zone T $\approx$10,000 days, the width and length of the zone is determined by hydrodynamic equation taking into consideration the following assumption.

a) The well field and adjacent areas are homogenous: This assumption will increase the protection zone since the adjacent areas of the well field have relatively very low transmissivity.

b) The natural protection of the well field is not considered for calculation of the third protection zone and the following aquifer parameters of the well fields are applied.

$t \approx 10{,}000$ day
$i \approx 0.001$
$H \approx 100$ meters (thickness of aquifer)
$T = 27636\ m^2/day$

Expected abstraction of ground water from the well field

$Q\ min \approx 30{,}000\ m^2/day$
$Q\ max \approx 200{,}000\ m^2/day$

Positions of the groundwater divide due to exploitation of the well field (xp)

$$X_p = \frac{Q}{2\Pi q} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where x_p - position of water divide (m)

Q - abstraction of water from the well field (m^3/day)

q - natural groundwater flow to the well field per linear meter.

q =Ti = 27636 * 0.001
= 27.6 m2/day

Assuming a large abstraction of groundwater from the well field about 200,000 m^3/day, the position of the neutral zone is determined by formula (3) is x_p = 1441 meters.

The length and width of the third protection zone calculated from analytical formulas are 18.4 KM and 4.0 km respectively (fig.11).

6.5. *Impact of Wastewater Plants and Sludge Disposal sites on Akaki Well field*

Except Akaki proposed waste water treatment plant all the others existing and proposed treatment plants (Kotebe, Kalite and Bole proposed) are outside the indicative outer zone or third protection zone (fig.11). Besides being outside third zone, especially kaliti treatment plant is located on thick impermeable clay, which is a natural protection for the groundwater of the area.

Akaki proposed treatment plant is located very near to Akaki well field. Here is recommended to shift about 3-4 km west of the present location to a location where the ground water is naturally highly protected and out of the outer protection zone.

Preliminary calculation of infiltrated contaminated water from Kaliti treatment plant for the size of 200 X 1400 meters shows that the maximum possible infiltration from the ponds is about 600 m^3/day. It should be this amount of water would reach Akaki well field after 10,000 days operation of the plant and during this time all of bacteriological and biological contaminates and most chemical contaminates will be attenuated.

Assuming piston type flow the only chemicals that reach the well field are those stable chemicals that do not change their properties due to physico-chemical interaction of the groundwater and rocks moving through.

If such chemicals are going to be treated in the treatment plants their effect can be evaluated applying the blending condition with the fresh groundwater by the following formula.

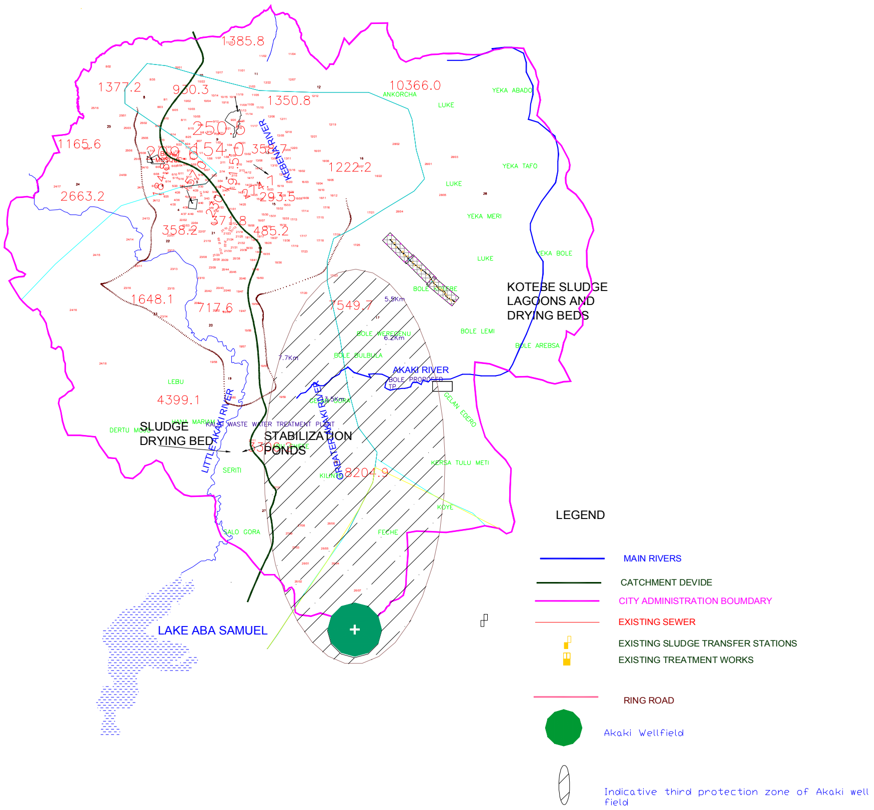
$$C_{bi} = (C_{ci}Q_c + C_{fi}Q_f)/(Q_c+Q_f) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where,

C_{bi} - Concetration of ith chemical in the blended water.
C_ci - Concetration of ith chemical in the contaminated water
C_{fi} - Concetration of ith chemical in the fresh ground water
Q_c - Volume of infiltrating contaminated water (m^3/day)
Q_f - Volume of abstracted water from the well field (m^3/day)

Fig.11

FIG.11 PROPOSED WASTE WATER DISPOSAL SITES, INDICATIVE THIRD ZONE OF PROTECTION



7. Conclusion and Recommendation

7.1 Conclusion

The groundwater study of Addis Ababa area indicates that;

- The thickness of clay deposit and subsurface infiltration depends on topography and geomorphology i.e. the plain part of the town (Bisrate Gebriel, Kaliti and Akaki areas) is covered by thick clay more than six meters of very low hydraulic conductivity and the large part of the town is covered by thin clay deposit less than three meters.

- The groundwater condition of Addis Ababa area is characterized as:

  a) The general groundwater flows direction within the city is from north to south.

  b) Transmissivity, bore holes yield, depth of groundwater and total dissolved solids increases from north to south direction. There are exceptions at some places of the town, which have high yield and total dissolved solids caused by intensive fracturing and thermal effect respectively.

  c) Analysis of bore holes log data revealed that the central part of the city elongated in the north-south direction (Filwoha, Llideta, Kality areas, etc.) exhibits confined groundwater condition.

- The groundwater Addis Ababa which is unconfined and groundwater depth is less than 80 meters is considered highly vulnerable to many pollutant except those highly absorbed and or readily transformed. The semi-confined aquifers of Addis Ababa area are considered as low vulnerability area due to the existence of Semi-impermeable strata between the groundwater level and source of contaminant, which prolongs the travel time to reach the groundwater. The confined zone of the groundwater of Addis Ababa area is considered negligible vulnerability to pollution due to the high confinement of the groundwater with impermeable strata.

- Akaki well field is found in highly naturally protected zone of Addis Ababa area. The analytical calculation of the third protection zone indicates that Except Akaki proposed wastewater treatment plant all the others existing and proposed treatment plants (Kotebe, Kalite and Bole proposed) are outside the indicative outer zone or third protection zone.

- Akaki proposed treatment plant is located very near to Akaki well field. Here is recommended to shift about 3-4 km west of the present location to a location where the ground water is naturally highly protected and out of the outer protection zone.

7.2 Recommendation

As discussed earlier the study was conducted on secondary data of previous studies and archive data. This condition makes this study a preliminary impact analysis of existing and proposed wastewater treatment plant / sludge disposal sites. Therefore, the following investigations are recommended to verify the natural protectiveness of the existing and proposed sites and monitor the impact of these sites on the groundwater.

To verify the natural protectiveness of these sites the following investigation should be carried on each existing and proposed treatment/ sludge disposal sites;

i) Geophysical investigation (vertical electrical sounding (VES) and electrical profiling) to determine the thickness of the clay deposit, the recommended number of VES about five AB/2=100 meters. Electrical profiling AB/2= 20 meters number of stations 21.

ii) Test pits excavation/auguring to determine the thickness of clay deposit and calibrate the geophysical investigation and conduct in-situ permeability tests, recommended three test pits maximum depth 6-7 meters for each site.

iii) Borehole drilling is recommended for Akaki proposed site, since the thickness of the clay deposit is very large. The borehole will be drilled with the objective of determining the thickness of clay, conduct in-situ permeability at different depth and use it as monitoring well.

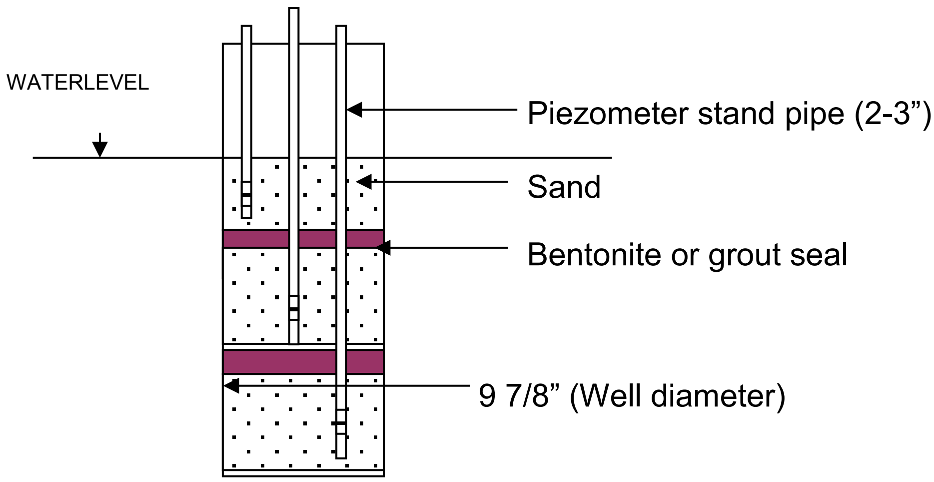
To carry out monitoring of the impact of the treatment plants / sludge disposal sites on the groundwater, monitoring of water quality on wells should be carried out.

The monitoring can be conducted on borehole drilled south of the treatment plants/ sludge disposal sites since the groundwater flow is from north to south direction. The monitoring well will be designed as given in fig.12. The water quality monitoring is recommended to be carried at three levels in each well.

Here is recommended to use data loggers and laboratory analysis for constant monitoring of the impacts of the treatment plants on the groundwater.

On each site, one borehole is recommended, as monitoring well and data loggers should be installed capable to record daily water level, temperature, conductivity and dissolved oxygen. Water samples should be collected monthly and laboratory analysis should be carried for water quality parameters recomended by the Environmentalist.

Fig.12 Schematic Drawing Multiple piezometers Installation



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