# Application of Geographic Information System (GIS) for Groundwater Resource Management: Practical Experience from Groundwater Development & Water Supply Training Center

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## Abstract

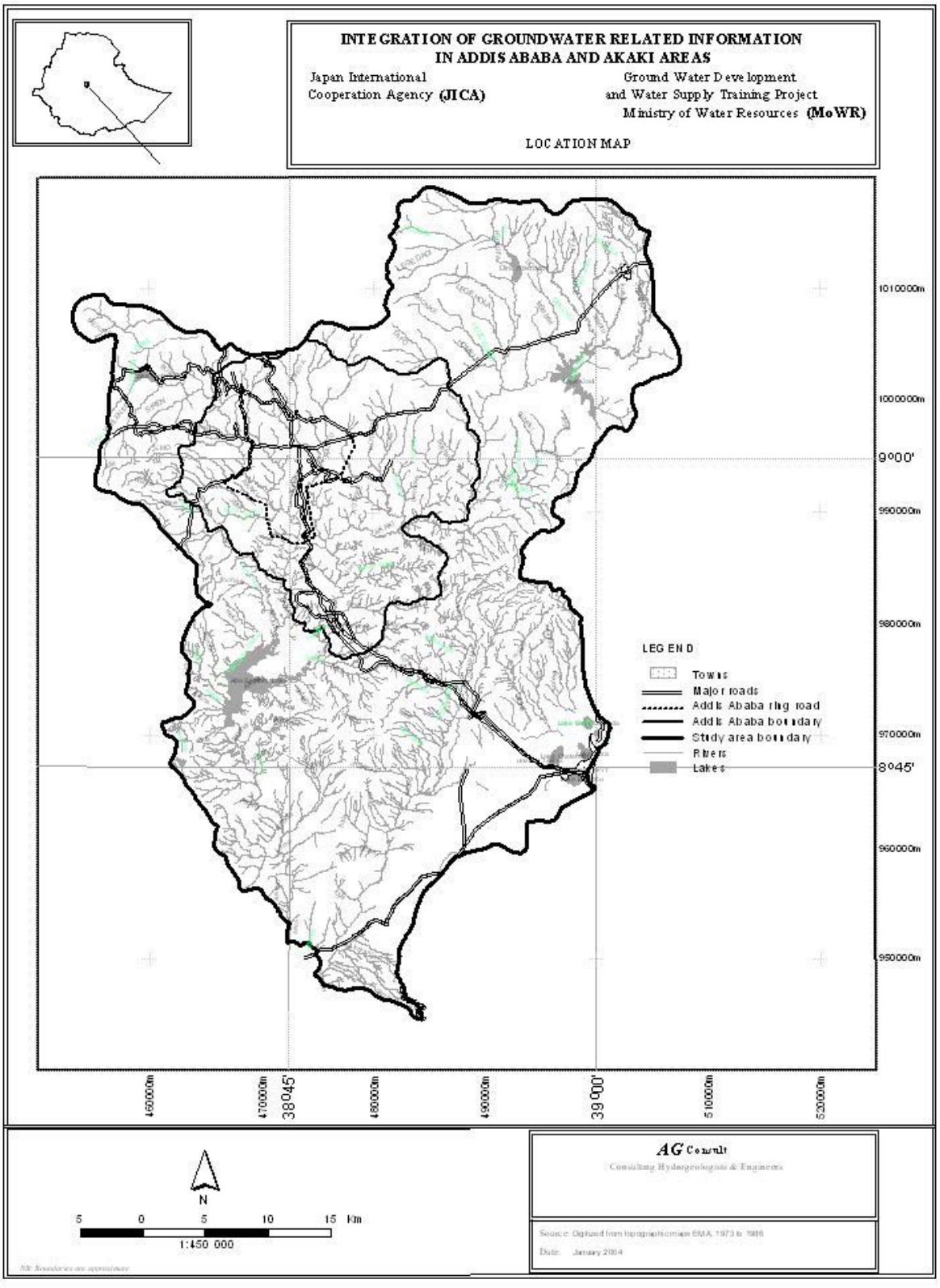
GIS is one of the most important tools for integrating and analyzing spatial information from different sources or disciplines. It helps to integrate, analyze and represent spatial information and database of any resource, which could be easily used for planning of resource development, environmental protection and scientific researches and investigations. Although its importance is widely known and implemented in many countries in the world, in Ethiopia except some applications for specific projects it is not well implemented for planning, resource management and environmental protection at a national or regional levels. The Groundwater Development and Water Supply Training Center has commenced training in GIS using spatial data from Addis Ababa area. In this paper it is presented to indicate the importance of GIS in groundwater resources management based on GIS assisted groundwater resources assessment of the Akaki & Dukem catchment.

## Introduction

Groundwater Development and Water Supply Training Center which is established with the joint effort of the Ministry of Water Resources (MoWR) and Japan International Cooperation Agency (JICA) has initiated a project that would organize relevant data / information and materialize the practical application of Geographic Information System (GIS) for groundwater resource management training.

Different spaital data were integrated and an over all picture about the groundwater resource condition of the Akaki & Dukem catchment was defined. The integrated spatial information helped to obtain information regarding the geological environment, the groundwater potential, the aquifer system characteistics & abstraction rates and the water quality conditions of the study area.

The project has indicated that the need for integration of information & data is critically important to know the groundwater potential and thereby to design sustainable development strategy which would enable to utilize the resource with out affecting the environment.


INTEGRATION OF GROUNDWATER RELATED INFORMATION
IN ADDIS ABABA AND AKAKI AREAS
Japan International
Cooperation Agency (JICA)
Ground Water Development
and Water Supply Training Project
Ministry of Water Resources (MoWR)
LOCATION MAP
LEGEND
Towns
Major roads
Addis Ababa ring road
Addis Ababa boundary
Study area boundary
Rivers
Lakes
1010000m
1000000m
9°00'
990000m
980000m
970000m
8°45'
960000m
950000m
460000m
470000m
38°45'
480000m
490000m
39°00'
510000m
520000m
N
5 0 5 10 15 Km
1:450 000
AG Consult
Consulting Hydrogeologists & Engineers
Source: Digitized from topographic maps EMA, 1973 to 1986
Date: January 2004

## Discussion

The project area covers 2212 $Km^2$ which includes the whole of Addis Ababa City, Akaki, Dukem, Debre Zeit, Sendafa and Alem Gena towns.

Akaki & Dukem Rivers are the two major rivers that do exist with in the project boundary. Akaki mainly originates from Intoto Mountain and drains to the south and at the end join Awash River. The river covers a Catchment area of 1658 $Km^2$ up to Awash River. On the other hand, Dukem River originates from Yerer Mountain and drains to the southwest and enters into Awash River covering 554 $Km^2$.

There are natural and artificial lakes with in the project boundary. The natural lakes (Bisofttu, Hora, Chelehleka, Bishoftu Guda, Kuriftu) exist around Debre Zeit area and the artificial ones located around Addis Ababa and its environs (Gefersa, Legedadi, Dire, Aba Samuel).

Data of 571 boreholes have been collected, out of which 563 boreholes occur within the study boundary. Among these boreholes Addis Ababa Water and Sewerage Authority (AAWSA) owns 91 boreholes. Private and government institutions, rural villages, Sendafa, Dukem, Debrezet and Alem Gena Water Supply Offices own the other wells.

Physico-chemical analyses results have been collected from 179 boreholes and 7 springs in the project area. By employing several techniques of reliability test of the data, 172 bore holes' data and 7 springs' data are qualified for further interpretations.

The spatial data collected have been analyzed and a number of maps have been produced among which the major ones are presented in this paper.

***Groundwater Table Map***

The groundwater table map, which is prepared, based on the spatial data analysis shows that the water tables in the study area ranges between 1750 and 2500m. The groundwater table map further indicates a regional groundwater flow direction from north to south direction following the general trend of Akaki river flow direction.

There are also very local flow trends available at some places. For instance in Akaki well field a local flow trend in southwest direction is observed. In Dukem and Debre Zeit areas the flow direction changes towards the southwest direction.

In areas where groundwater potential is higher such as Akaki well field and Debre Zeit areas the spacing between the groundwater contours seen to become larger indicating higher transmissivity values.

The groundwater table contour map generally shows a continuity of groundwater flow from north to south showing somehow the continuous groundwater flow from one aquifer system to the other.

***Depth to Groundwater Level Map***

Depth to groundwater ranges from shallow groundwater levels close to the ground surface to a depth of over 200m. Shallow groundwater is mainly concentrated in the central and northern parts of the Akaki Catchment. However, the groundwater is deeper around Dukem area where the depth ranges between 50 & 100 meters.

The groundwater is deep up to 100 m and at times over 200 m in the mountainous areas and between Akaki well field and Dukem plain. In the Akaki well field the depth to groundwater table ranges between 50 to 75 meters.

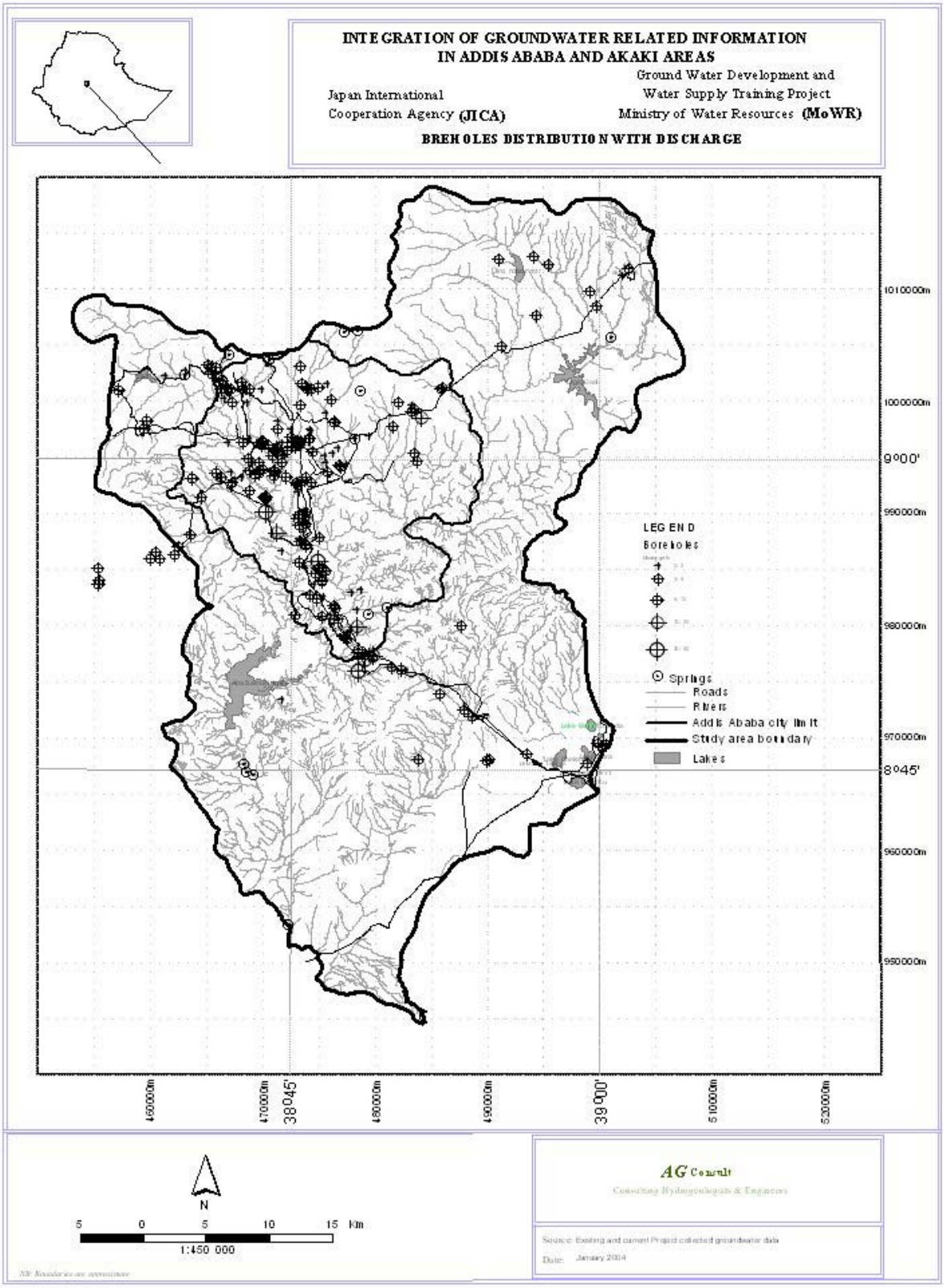
***Water Quality Maps***

Different water quality maps have been produced using point data spatial analysis of GIS. The following water quality parameters have been selected and their respective maps have prepared believing that the analytical results would indicate the water quality conditions of the project area.

*Total Dissolved Solids (TDS) Map*

The TDS map indicates the presence of higher value that falls in the range of 600mg/l to over 1500mg/l in the central Addis Ababa and Akakai well field and at the hot springs of Awash River. The high TDS value in the central part would be as the result of hot springs (Filwuha springs). In Akaki well field the TDS values which ranges between 600mg/l to 1000mg/l have been noticed. This is may be from the impact of deeply circulating hot water as this is encountered from the deep test borehole (TW1) having a depth of 300 meter and a temperature of 35 $^{0}$C.

In general 175 water samples fall within the TDS range for freshwaters and among them 161 samples are characterized by relatively low mineral content. Three water sources are identified being brackish groundwater. The interpreted water quality with respect to TDS indicate that more than 90% of the study area groundwater lie in good range for drinking water purposes. The spatial distributions of the Total Dissolved Solids (TDS) values are shown on the TDS Map.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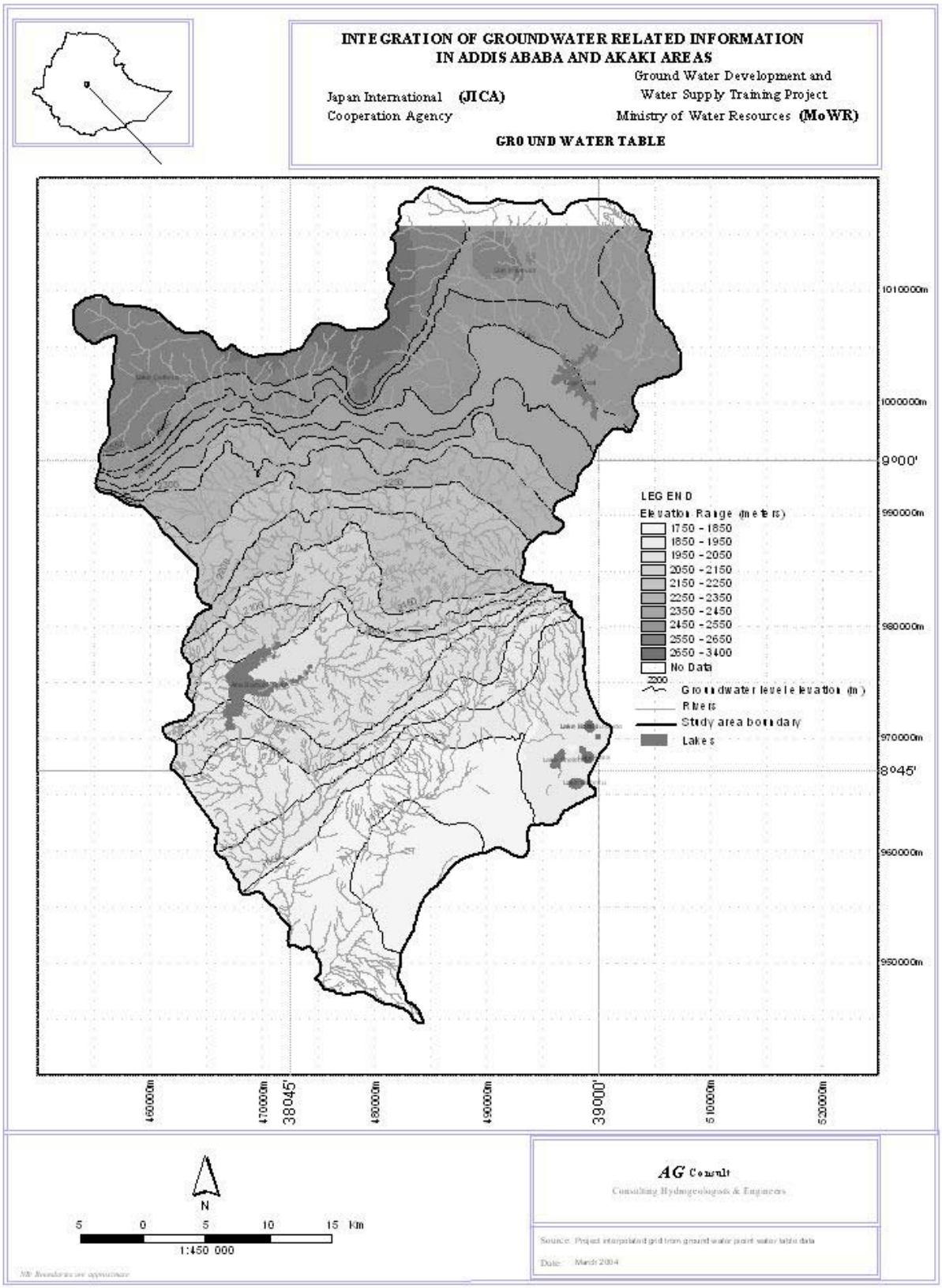
BREHOLES DISTRIBUTION WITH DISCHARGE
LEGEND
Boreholes
Springs
Roads
Rivers
Addis Ababa city limit
Study area boundary
Lakes
1010000m
1000000m
9°00'
990000m
980000m
970000m
8°45'
960000m
950000m
450000m
470000m
38°45'
480000m
490000m
39°00'
510000m
520000m
N
5 0 5 10 15 Km
1:450 000
AG Consult
Consulting Hydrogeologists & Engineers
Source: Existing and current Project collected groundwater data
Date: January 2004


INTEGRATION OF GROUNDWATER RELATED INFORMATION
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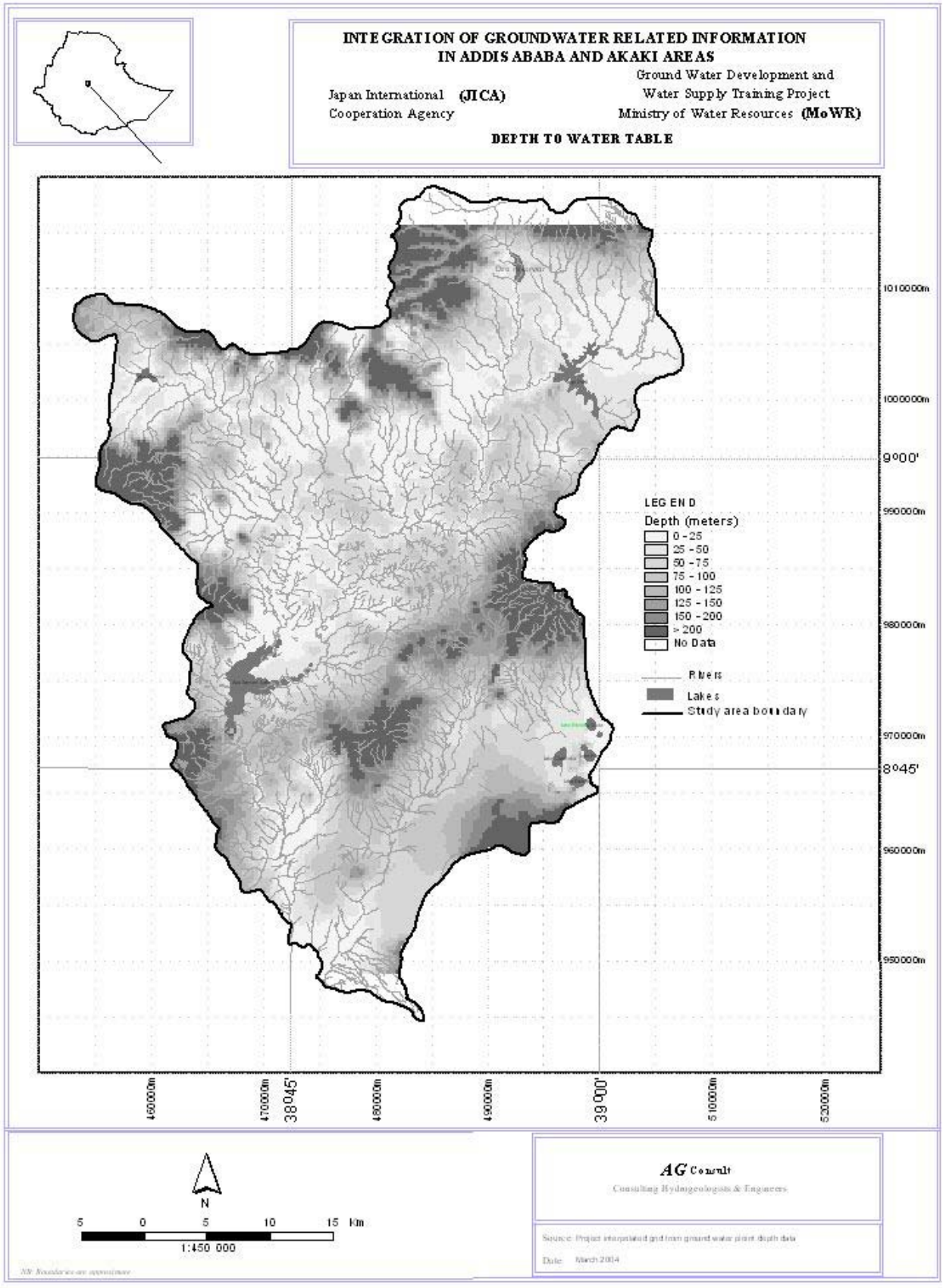
Ground Water Development and Water Supply Training Project
Ministry of Water Resources (MoWR)
GROUND WATER TABLE
LEGEND
Elevation Range (meters)
1750 - 1850
1850 - 1950
1950 - 2050
2050 - 2150
2150 - 2250
2250 - 2350
2350 - 2450
2450 - 2550
2550 - 2650
2650 - 3400
No Data
2200
Groundwater level elevation (m)
Rivers
Study area boundary
Lakes
1010000m
1000000m
9°00'
990000m
980000m
970000m
8°45'
960000m
950000m
460000m
470000m
38°45'
480000m
490000m
39°00'
510000m
520000m
N
5 0 5 10 15 Km
1:450 000
AG Consult
Consulting Hydrogeologists & Engineers
Source: Project interpolated grid from ground water point water table data
Date: March 2004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Ground Water Development and Water Supply Training Project
Ministry of Water Resources (MoWR)
DEPTH TO WATER TABLE
LEGEND
Depth (meters)
0 - 25
25 - 50
50 - 75
75 - 100
100 - 125
125 - 150
150 - 200
> 200
No Data
Rivers
Lakes
Study area boundary
1010000m
1000000m
9°00'
990000m
980000m
970000m
8°45'
960000m
950000m
38°45'
39°00'
N
5 0 5 10 15 Km
1:450 000
AG Consult
Consulting Hydrogeologists & Engineers
Source: Project interpolated grid from ground water point depth data
Date: March 2014

*Hardness Map*

Total hardness as $CaCo_3$ in mg/l map shows that values ranging between 100 - 300 mg/l represent the major part of the study area. Lower values ranging between 60 -100mg/l and below 60 mg/l occur towards the norteast and north west of the Akaki Catchment. High values over 300 mg/l observed in the central Addis Ababa which is attributed to the influence of Filwuha (hot ground water.

The higher values noticed at Akaki well field may be accounted to the hot groundwater encountered at depth in the well field where the temperature recorded to be 30 $^0$C. It has been found that 27 boreholes are found to be soft water and 9 water sources are identified being very hard groundwater. The interpreted water quality with respect to Hardness indicates that 68% of the study area groundwater lies in good range for drinking water purposes. The spatial distributions of the hardness values are shown on the hardness map.

*Nitrate Map*

Nitrate is one of the major stable chemical that indicated potential human impacts. High Nitrate values over 10 mg/l are obtained in the central Addis Ababa, around Akaki and Awash hot springs. In natural condition the Nitrate value should not exceed 10 mg/l. Excedence of this value shows human influence on th egroundwater system and further study becomes necessary to define propely the exact causes.

It has been found that 132 water samples are found to be having relatively low nitrate concentrations. Seven water sources are identified having very high nitrate concentrations, which are well above World Health Organization's and National drinking water guideline values. Thirty-nine boreholes' nitrate concentrations also indicate the vulnerability of the respective groundwater sources. The interpreted water quality with respect to nitrate concentrations indicate that more than 70% of the study area groundwater lies in good range for drinking water purposes having very low level of nitrate. The spatial distributions of the nitrate values are shown on the Nitrate Map.

# INTEGRATION OF GROUNDWATER RELATED INFORMATION IN ADDIS ABABA AND AKAKI AREAS

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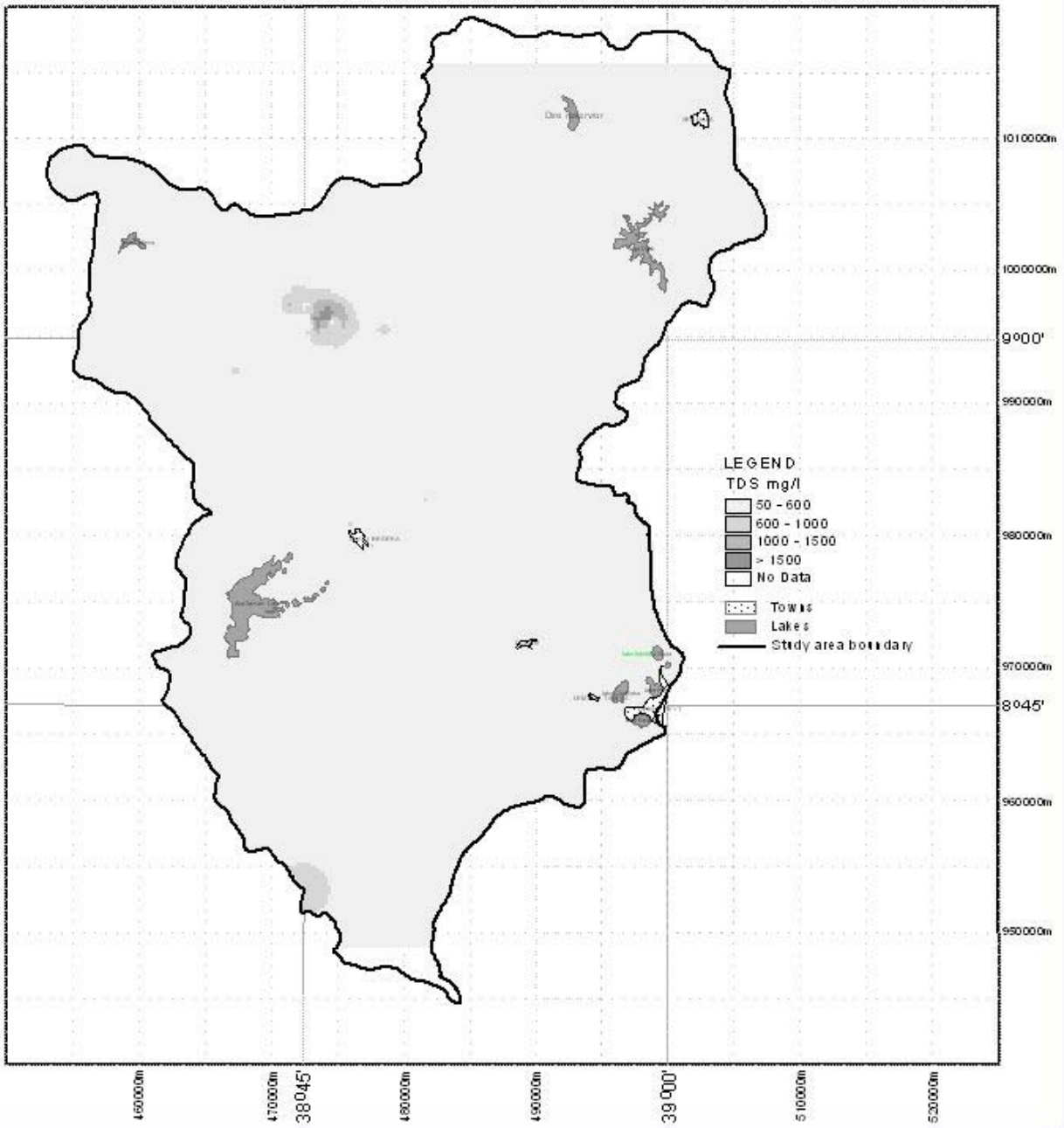
## TOTAL DISSOLVED SOLIDS




N

5 0 5 10 15 Km

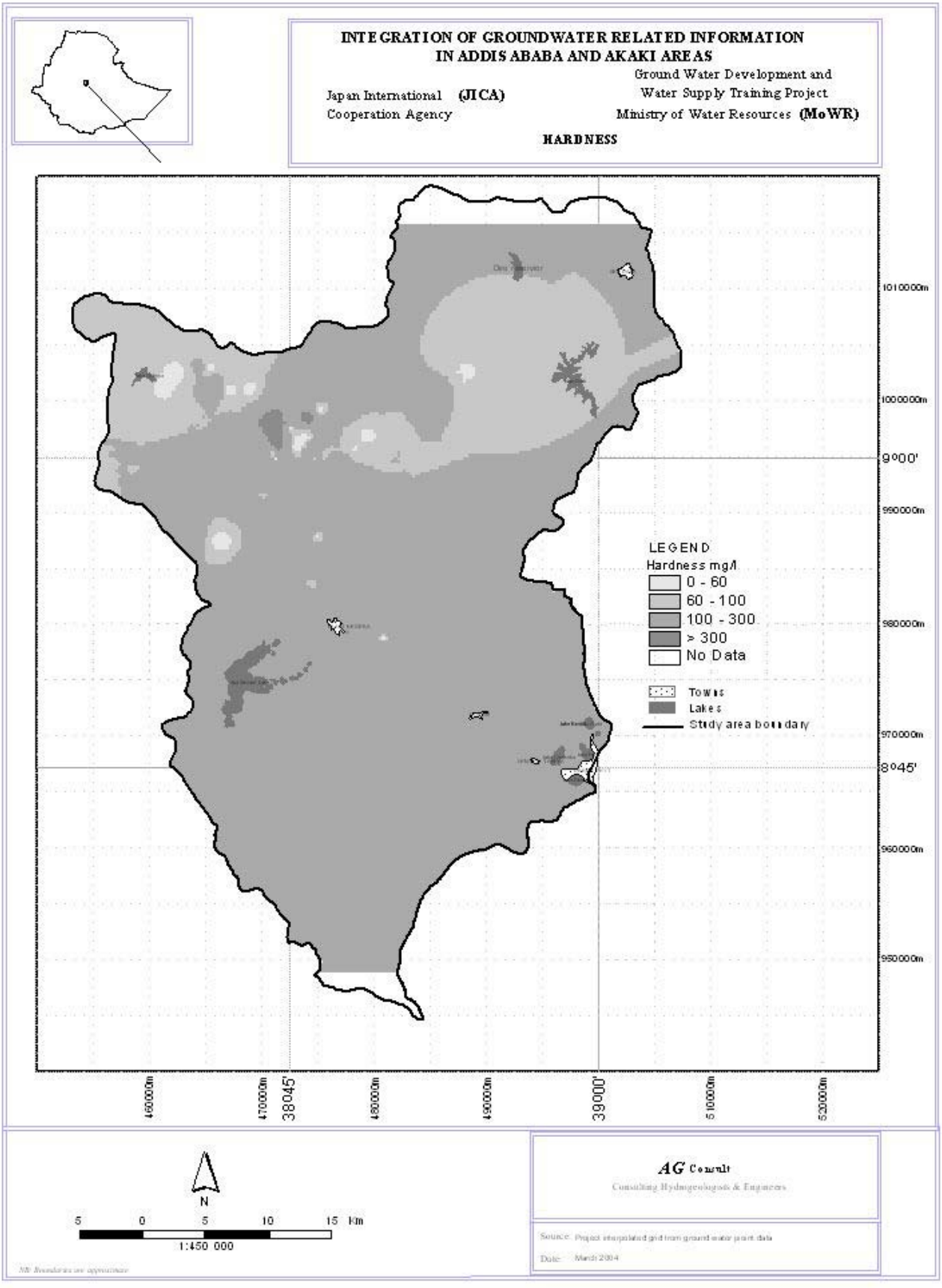
1:450 000

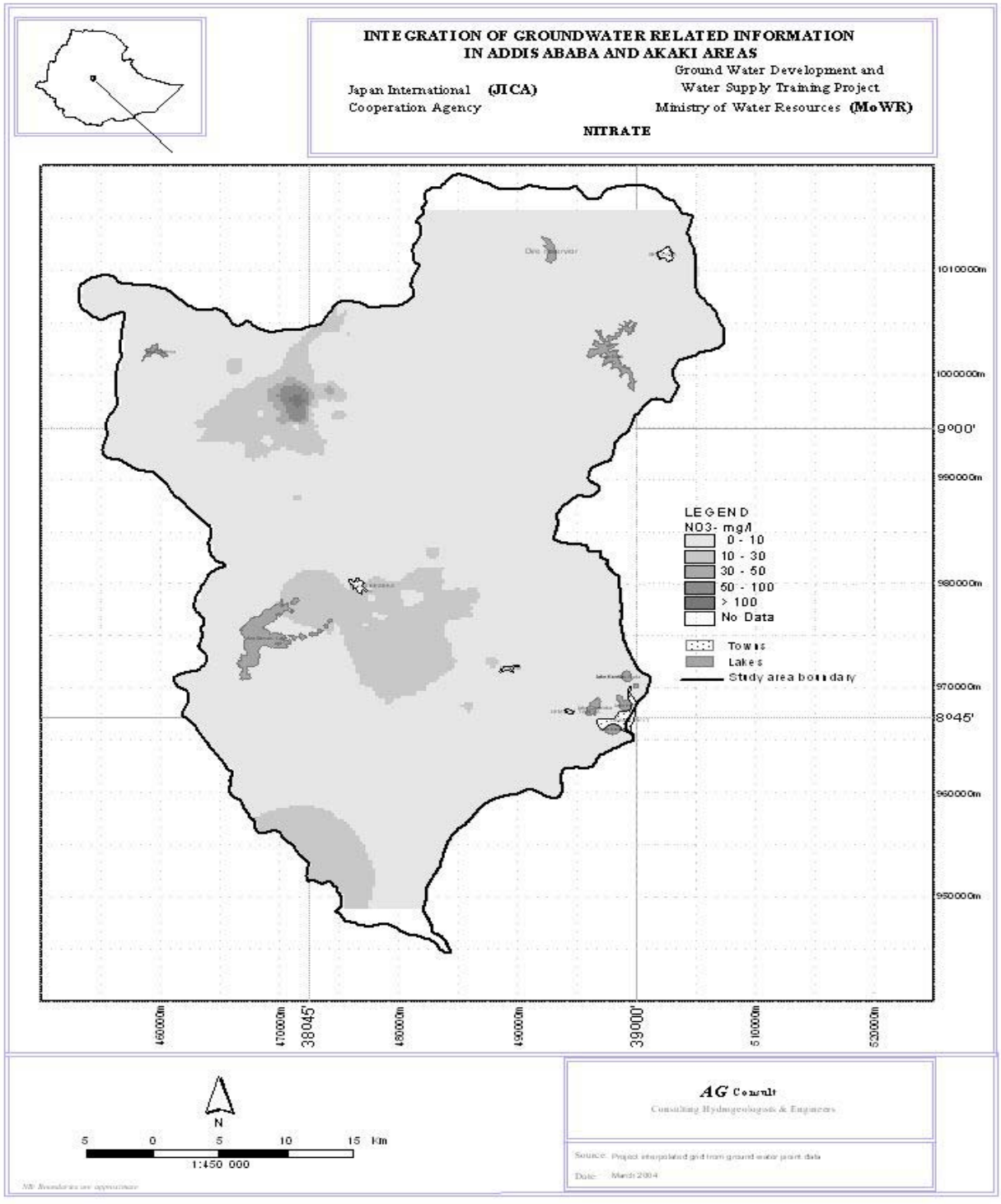
*NB: Boundaries are approximate*

**AG** Consult
Consulting Hydrogeologists & Engineers

Source: Project interpolated grid from ground water point data

Date: March 2004


INTEGRATION OF GROUNDWATER RELATED INFORMATION
IN ADDIS ABABA AND AKAKI AREAS
Japan International Cooperation Agency (JICA)
Ground Water Development and Water Supply Training Project
Ministry of Water Resources (MoWR)
HARDNESS
LEGEND
Hardness mg/l
0 - 60
60 - 100
100 - 300
> 300
No Data
Towns
Lakes
Study area boundary
1010000m
1000000m
9°00'
990000m
980000m
970000m
8°45'
960000m
950000m
460000m
470000m
38°45'
480000m
490000m
39°00'
510000m
520000m
N
5 0 5 10 15 Km
1:450 000
AG Consult
Consulting Hydrogeologists & Engineers
Source: Project interpolated grid from ground water point data
Date: March 2004
NB: Boundaries are approximate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NITRATE
LEGEND
NO3- mg/l
0 - 10
10 - 30
30 - 50
50 - 100
> 100
No Data
Towns
Lakes
Study area boundary
1010000m
1000000m
990000m
980000m
970000m
960000m
950000m
9°00'
8°45'
460000m
470000m
480000m
490000m
500000m
510000m
520000m
38°45'
39°00'
N
5 0 5 10 15 Km
1:450 000
AG Consult
Consulting Hydrogeologists & Engineers
Source: Project interpolated grid from ground water point data
Date: March 2004

***Groundwater Data Analysis Results***

Out of the total 571 inventoried wells 331 boreholes are functional. Amongst the 331 functional wells current discharge rate are obtained only for 278 wells (84%).

From the total number of wells in the study area AAWSA owns 91 boreholes. Out of these 33 boreholes were drilled as test wells, 4 as monitoring wells and 54 as production boreholes. Out of the 54 production boreholes presently only 24 are operational.

The total volume of water currently abstracted from the study area is estimated to be about 878 L/s. Out of these total amount 769 l/s is obtained from Akaki River Catchment and the remaining 74 l/s from Dukem River Catchment.

From the total of 769 l/s of water that is produced in the Akaki Catchment, AAWSA produces 71% that is 547 l/s. Private and other government institutions produce the remaining 257 l/s. AAWSA produces about 347 l/s or 63 % of its total production from Akaki Well field. The other 37 % are produced from other localities within the Akaki River Catchment.

The current production of groundwater over the whole of the study boundary, which is 878 l/s amounts 25 % of the estimated recharge.

Currently the total production from Akaki Catchment is about 32 % of the total recharge out of which 28 % is AAWSA's production. For a volcanic aquifer such amount of production rate is high. Unless proper groundwater management strategy implemented, in such condition the groundwater resource may become at risk.

## Conclusion

The GIS assissted database system would help to apply groundwater managemnt practices such as; proper groundwater resource management in terms of groundwater qulaity & quantity, Integrated management of water, landuse and the environment; to optimize pumping rates with respect to the capacity of the aquifer system, and to prevent groundwater quality deterioration through proper monitoring & evaluation.

The produced groundwater related database could help as information source to Institutions, researchers, groundwater practitioners, drilling companies and decision makers etc. Institutions like Addis Ababa Water & Sewerage Authority (AAWSA), Ministry of Water Resources, Environmental Protection Agency, Science & Technology Commission, Geological Survey of Ethiopia, Addis Ababa University, etc would benefit from the out comes of this study.

The database would serve as an important information source for future updating of the Akaki Groundwater Model.

On the other hand, currently, many urban centers and rural villages in Ethiopia are using groundwater as potable water source. However, there is no well organized and integrated groundwater resources database system at National and Regional levels.

In order to perform proper groundwater resource assessment, and to apply the subsequent exploitation and sustainable management the need for having well-organized spatial data / information cannot be over looked. Hence establishing *GIS assisted Groundwater Data Base system* at Regional & National level should be considered for the future.

The current training effort by the institute towards the Integration of Groundwater Related Information through application of GIS should be considered as an example for realization of local and / or national groundwater database system. Once trained man power is avilable, by strengthning institutional setup it would be possible to establish data base centers which can be networked throughout the country

Currently there is no well organised institution with a responsibility for organisation, management and dessimination of groundwater related data at national and regional levels. Therefore, side by side with the manpower training and capcity building efforts have to be exerted towards creating respnsible instituions.

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