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Report on the Workshop *Geochemistry Applied to Water Resource Issues in Africa* held at Sodere, Ethiopia 25-30 September 1995

by W G Darling, W M Edmunds and P L Smedley

This report was prepared for the Hydrogeology Series

Bibliographic Reference

Authors: W G Darling, W M Edmunds and P L Smedley

1 INTRODUCTION

The task of TDR Project 12FW (ODA Project D00123) has been to arrange and carry out an interactive workshop meeting on geochemistry applied to water resource issues in sub-Saharan Africa. British Council support for participants has been an integral part of this process. A previous report (WD/95/9R) described a reconnaissance visit to Ethiopia to liaise with the Ethiopian Institute of Geological Surveys (EIGS, the counterpart organisers) and the British Council over the location, format and programme of the Workshop. The present report describes the holding of the workshop in late September 1995.

2. ITINERARY

22 September	Travel overnight to Addis Ababa.
23 September	Meeting with Ato Berhanu Gizaw, EIGS convener, over organisational details.
24 September	Further meeting with Ato B Gizaw and telephone contact with representatives of the British Council.
25 September	Travel to Sodere and start of the Workshop. Participant presentations and discussions commence.
26 September	Participant presentation and discussion sessions continue.
27 September	Mid-session field excursion to the Awash National Park.
28 September	Participant presentation and discussion sessions continue.
29 September	Demonstration of field sampling techniques. Discussion of framework for future cooperation. Closing of the Workshop.
30 September	Return to Addis Ababa. Round-up discussions with Ato B Gizaw.
1 October	Return to UK.

3. WORKSHOP PROGRAMME

The Workshop was officially declared open by Ato Shemsudin Ahmed, Vice-Minister of the Ministry of Mines and Energy, in the presence of the Chief Geologist of the EIGS, Ato Ketema Tadesse. The British Council was represented by Ato Tsegaw Checkole. Some 15 water scientists from Ethiopian institutions attended, together with 12 scientists from 10 other African countries (details in Appendix 1).

Full details of the Workshop programme are given in Appendix 2. While attempts were made to group participant presentations into sessions with a common theme, this did not always prove possible. However, the small size of the workshop and its single session structure meant that this was not in practice a disadvantage. The abstracts for most presentations are given in Appendix 3.

The mid-session field excursion to the Awash National Park covered various aspects of geology and hydrogeology, more fully described in the itinerary (Appendix 4).

The practical demonstration of field sampling and measurement techniques was carried out on one of the Sodere hot springs by EIGS personnel (concentrating on geothermal aspects) and the BGS team (concentrating on redox and isotopic aspects).

After a discussion session on a framework for future cooperation on the application of geochemistry to African water resource issues, the Workshop was officially closed by Dr Robert Monro, Assistant Director of the British Council in Ethiopia.

During the course of the workshop, authors of previously-submitted draft manuscripts for consideration for the planned thematic issue of the Journal of African Earth Sciences were advised of any changes necessary to bring their papers to a satisfactory state for peer review.

4. DISSEMINATION OF INFORMATION

As part of their registration package, participants received a copy of *Field sampling methods for groundwater-quality investigation*, based on a condensed version of a previous BGS report (WD/89/56), and a copy of *Groundwater Quality* (Eds H Nash and G J H McCall), published by AGID in association with Chapman and Hall. Five out of the 20 chapters in this book were contributed by BGS authors.

Two deliverables have resulted from the Workshop. The first of these is a framework document for future water quality studies in the sub-Saharan countries (Appendix 5), which is the outcome of discussion during the last session of the Workshop, and subsequent iterative comments by the participants. The second is the thematic issue of the Journal of African Earth Sciences referred to in (3) above, scheduled for publication in the first half of 1996.

APPENDIX 1

Workshop on Geochemistry Applied to Water Resource Issues in Africa:

List of participants and their addresses

CAMEROON

Gregory Tanyileke
Institute For Geological and Mining Research (IRGM)
BP 4110
Yaounde
Cameroon
Fax +237 201854
Tel +237 210316

DJIBOUTI

Ibrahim Houssein
Dept of Geochemistry
ISERST
BP486
Djibouti
Republic of Djibouti
Fax +253 354812
Tel +253 352795

ERITREA

Habteab Zerai
Department of Water Resources
Ministry of Energy, Mines & Water Resources
POB 1488
Asmara
Eritrea
Fax +291 1 124625
Tel +291 1 119636

ETHIOPIA

Fanta Demissie
Ethiopian Science and Technology Commission
PO Box 2490
Addis Ababa
Ethiopia
Fax +251 1 518829
Tel +251 1 511344

Ghirma Moges
Department of Chemistry
Addis Ababa University
PO Box 1174
Addis Ababa
Ethiopia
Fax +251 1 552112
Tel +251 1 126276

Juneidi Sado
Addis Ababa Water and Sewage Authority
PO Box 4661
Addis Ababa
Ethiopia
Tel +251 1 550769

Wagaye Teshome
Water Resources Development Authority
PO Box 5673
Addis Ababa
Ethiopia
Fax +251 1 613279
Tel +251 1 613929

Berhanu Gizaw, Kibret Beyene, Meseret Teklemariam, Negussie Mekuria, Salahadin Ali and Tafesse Gizaw
Geothermal Exploration Project
Ethiopian Institute of Geological Surveys
PO Box 40069
Addis Ababa
Ethiopia
Fax +251 1 712033/513877
Tel +251 1202858/712855

Gebretsadik Eshete, Getahun Kebede and Zenaw Tessema
Department of Hydrogeology, Engineering Geology and Geothermal
Ethiopian Institute of Geological Surveys
PO Box 2302
Addis Ababa
Ethiopia
Fax +251 1 513877
Tel +251 1 202851/712855

Sinknesh Egigu and Sisay Engida
Central Geological Laboratory
Ethiopian Institue of Geological Surveys
PO Box 2302
Addis Ababa
Ethiopia
Fax +251 1 513877
Tel +251 1 202415/712855

GHANA

Anthony Amuzu
Water Resource Research Institute (CSIR)
PO Box M.32
Accra
Ghana
Fax +233 21 777170
Tel +233 21 775351/776044

KENYA

Musa Arusei
Moi University
PO Box 3900
Eldoret
Kenya
Fax +254 321 43047/43149
Tel +254 321 43001-8/43620

Theophilus Davies
Department of Geology
University of Nairobi
PO Box 30197,
Nairobi
Kenya
Fax +254 2 449539/446138/336885
Tel +254 2 449233
(Now at Moi University, address and contact nos. as for Prof Tole)

Mwakio Tole
Environmmental Studies
Moi University
PO Box 3900
Eldoret
Kenya
Fax +254 321 43149
Tel +254 321 43119

SENEGAL

Cheikh Gaye
Dept of Geology
Universite de Dakar
BP 5005
Dakar-Fann
Senegal
Fax +221 246318
Tel +221 203619

SOUTH AFRICA

Johanita Kotze
Department of Water Affairs
Private Bag X313
Pretoria
South Africa
Fax +27 12 3286397
Tel +27 12 2992674

TANZANIA

Hudson Nkotagu
Technical University
SFB 69
Ackerstrasse 71-76
D-13355 Berlin, Germany.
Fax +49 30 314 72837
Tel +49 30 314 72646

UGANDA

John Karundu
Water Development Department
PO Box 19
Entebbe
Uganda
Tel +256 42 20914

UNITED KINGDOM

George Darling, Michael Edmunds and Pauline Smedley
British Geological Survey
Maclean Building
Wallingford
Oxon OX10 8BB UK
Fax +44 1491 692345
Tel +44 1491 838800

ZAMBIA

Paul Zambezi
c/o R N Zambezi
Care Zambia
PO Box 36238
Lusaka
Zambia
Fax +260 1 292080

Workshop on Geochemistry Applied to Water Resource Issues in Africa

Ethiopia, 25-30 September 1995

Programme

Monday 25 September

0800-1130	Travel to Sodere, with stop at Debre Zeit
1200-1220	Opening Ceremony: Addresses by the Conveners and Guest of Honour
1220-1300	Keynote lecture by W M Edmunds: *Geochemistry applied to water resource issues in Africa.*
1300-1600	Buffet lunch

First Session: Water in Ethiopia - chaired by **N Mekuria**

1600-1630	F Demissie: *The Ethiopian national mines, water, energy and geoinformation science and technology policy, with particular emphasis on the water sector.*
1630-1700	G Eshete: *The groundwater quality situation in Ethiopia.*
1700-1730	B Gizaw: *Geochemistry and geothermal energy-related problems.*
1900-	Dinner

Tuesday 26 September

Second Session: Impact of geological environment on water quality - chaired by **S Egigu**

0830-0900	T C Davies: *The geochemical behaviour of iodine in the natural waters of Kenya.*
0900-0930	P L Smedley: *Arsenic mobility in the Obuasi gold-mining belt of Ghana.*
0930-1000	M P Tole: *Some studies on pollution of natural waters in Kenya.*
1000-1030	P Zambezi: *The effect of geological/geochemical environment on sustainable groundwater supply in the Lusaka urban area.*
1030-1100	Coffee

Third Session: Aquifer recharge - chaired by **J Sado**

1100-1130	C B Gaye: *The use of environmental chloride and tritium to estimate total recharge to a Sahelian unconfined aquifer.*
1130-1200	W M Edmunds: *Estimation of recharge in semi-arid areas by unsaturated zone profiling techniques.*
1200-1230	J Karundu: *Packer tests and fissure hydrochemistry.*
1230-1400	Lunch

Fourth Session: Isotopic applications - chaired by **C B Gaye**

1400-1430	W G Darling: *Isotopes as indicators of water movement and chemical evolution in the East African rifts.*
1430-1500	J C Kotze: *The use of isotopes in the characterisation of the TMS aquifer, South Africa.*
1500-1530	H H Nkotagu: *Application of environmental isotopes in groundwater recharge studies in a semi-arid fractured crystalline basement area of Dodoma, Tanzania.*
1530-1600	Tea

Fifth Session: Water in the East African Rift Valley - chaired by **M P Tole**

1600-1630	M K Arusei: *Rainfall patterns and lake water level fluctuations in Lake Naivasha, Kenya.*
1630-1700	M Teklemariam & W G Darling: *Sodere and the Ethiopian Rift: geological and hydrological context*
1700-1730	B Gizaw: *The cause of high sodium bicarbonate and fluoride in the waters of the Lakes District, Ethiopian Rift Valley.*
1730-1740	Introductory talk for the mid-session field trip to the Awash National Park (Berhanu Gizaw)
1900-	Dinner

APPENDIX 3

Workshop on Geochemistry Applied to Water Resource Issues in Africa:

Abstracts of presentations

Edited by B Gizaw and W G Darling

AN OVERVIEW OF THE CHEMICAL CHARACTERISTICS OF GROUNDWATER SUPPLIES IN GHANA

Anthony T Amuzu

Water Resources Research Institute (CSIR), Box M32, Accra, Ghana

ABSTRACT

Boreholes equipped with hand-operated pumps are most economical for rural water supplies and these systems have been adopted for use in Ghana.

Compared with surface water, groundwater has obvious advantages as the quality in Ghana is generally good and there is no need for treatment. But in some parts of the country quality problems associated with excess iron, fluoride and salinity have been identified.

Iron may be of aquifer origin, or may be derived from aggressive groundwaters of pH 6.5 or less which attack non-corrosion-resistant down-the-hole pump parts to increase the iron concentration of the supplies. Supplies with iron of aquifer origin are being treated in prototype iron removal plants using aeration, sedimentation and filtration. Where the supplies are aggressive, corrosion resistant pump parts such as stainless steel and PVC are in use.

Biological iron enrichment deriving mainly from iron bacteria has not been studied.

High fluoride concentrations of up to 5.3 mgl^{-1} have been reported in the Northern Savannah Ecological Zone. A pilot defluoridation project using chemicals has been initiated for treatment at the household level. Saline groundwater supplies are not treated.

A STUDY TO INVESTIGATE THE POSSIBLE CAUSES OF WATER LEVEL FLUCTUATIONS IN LAKE NAIVASHA, KENYAN RIFT VALLEY.

Musa K Arusei

Department of Chemistry, Chepkoilel Campus, Moi University, PO Box 1125, Eldoret, Kenya.

ABSTRACT

Naivasha is a fresh water lake in the Kenyan rift valley with no surface outlet. It is fed by two perennial rivers, Malewa and Gilgil. It is situated at the culmination of the Kenyan rift valley with an altitude of 1884 m.a.s.l. The water level in the lake has been falling gradually since 1917. Total annual rainfall at meteorological stations in the water catchment of this lake has not changed significantly over the same period.

The rainfall data have shown that the fluctuations of water level in the lake may be controlled by the more pronounced groundwater fluctuations within its vicinity on the rift floor. Stable isotope data have shown that the groundwater sampled by the boreholes to the northeast and southeast of the lake flows into the lake. This study suggests that the lake may be an exposed groundwater body within the rift floor.

GEOCHEMISTRY AND GEOTHERMAL ENERGY RELATED PROBLEMS

Berhanu Gizaw

Ethiopian Geological Survey, PO Box 40069, Addis Ababa, Ethiopia

ABSTRACT

The rapid increases in the prices of fossil fuels, the growing realisation of the limited resources of these fuels and/or the environmental costs of energy production that are borne by society at large account for much of interest in geothermal energy today. This resource, occurring as natural steam and hot water, is a reliable, relatively clean and plentiful source of power for countries such as Ethiopia whose known hydrocarbon resources are only small. The applications of geochemistry in exploring and utilising geothermal resources are numerous. Geochemical techniques can provide information on:

- Type of geothermal system
- Subsurface fluid temperatures and pressures
- Range in composition and homogeneity of the hot fluids
- Origin, flow patterns and residence time of the fluids
- Nature of the reservoir rocks
- System permeabilities
- Mineral deposition potential of the fluids
- Natural heat flow
- Fluid constituents of possible commercial value
- Feasibility of reinjection to eliminate thermal and chemical pollution problems.

A brief review of the application of these techniques in the exploitation of this energy resource will be presented, with special emphasis on Ethiopian geothermal systems.

THE CAUSE OF HIGH SODIUM BICARBONATE AND FLUORIDE IN THE WATERS FROM THE LAKES DISTRICT, ETHIOPIAN RIFT VALLEY

Berhanu Gizaw

Geothermal Exploration Project, Ethiopian Geological Survey, P O Box 40069, Addis Ababa, Ethiopia

ABSTRACT

Thermal waters in the Lakes District part of the Ethiopian Rift Valley are characterised by high sodium, bicarbonate and fluoride concentrations, and near neutral pH. Sodium, bicarbonate and fluoride are positively correlated in the waters. Fluoride is essential for human beings to avoid dental caries but also causes fluorosis when the intake is high. The principal cause for high bicarbonate in the area is the high rate of carbon dioxide outgassing. Similarly, acid volcanics, geothermal heating, high carbon dioxide pressure, low calcium and low salinity are the main causes of the high fluoride level in this part of the Rift. The water chemistry and the mineralogy suggest that the system is undersaturated with respect to fluorite. Calcium tends to be fixed by calcium-bearing minerals such as calcite and epidote which are abundant in the system. Hence, it appears that fluoride is probably a mobile component in acid volcanic geothermal systems.

ISOTOPES AS INDICATORS OF WATER MOVEMENT AND CHEMICAL EVOLUTION IN THE EAST AFRICAN RIFTS

George Darling[1], Berhanu Gizaw[2] and Musa Arusei[3]

[1]British Geological Survey, Wallingford OX10 8BB, UK
[2]Ethiopian Geological Survey, PO Box 40069, Addis Ababa, Ethiopia
[3]Department of Chemistry, Moi University, PO Box 1125, Eldoret, Kenya

ABSTRACT

An understanding of regional hydrogeological patterns is vital to the assessment of water resources in the Ethiopian-Kenyan rift valley system, the floor of which is occupied by a string of lakes with varying chemical characteristics separated by volcanic terrain often semi-arid in climate. Stable O and H isotopes have an important role to play here, because evaporative enrichment of the lake waters provides a clear isotopic contrast to groundwaters flowing in from the side of the valley. These isotopes are therefore very effective in tracing flowpaths and mixing between the two main sources of water, and have even been used in areas where no springs or boreholes exist, by using the isotopic contents of geothermal steam (with appropriate correction) as a guide to water compositions at depth.

Stable O and H isotopes are primarily of use in assessing the physical aspects of water resources. As far as resource *quality* is concerned isotopes have a less important role, though study of ^{13}C in dissolved inorganic carbon appears to confirm the importance of silicate hydrolysis as an agent in the evolution of rift valley groundwaters, and can sometimes reveal evidence of more complex evolutionary processes. The cause of silicate hydrolysis, CO_2 outgassing, renders problematical the use of ^{14}C for groundwater dating, but indications are that most borehole waters are of relatively short residence.

THE GEOCHEMICAL BEHAVIOUR OF IODINE IN NATURAL WATERS OF THE KIAMBU AND ELDORET AREAS OF KENYA

Theophilus C Davies

Department of Geology, University of Nairobi, P O Box 30197, Nairobi, Kenya

ABSTRACT

Iodine concentration data are presented for surface and groundwaters in the Kiambu and Eldoret areas of Kenya, based on the analysis of thirty randomly selected samples. The analytical methodology - a colorimetric technique using long path length cells - gives a resolution of total iodine concentration to within ± 0.1 μgl^{-1}. The mean total iodine value obtained for groundwater is 10.0 μgl^{-1} which is well in excess of that for waters in iodine-deficient areas of the world (less than 2 μgl^{-1}). The mean value obtained for samples of river water is even higher (16.0 μgl^{-1}) though these were mainly impact samples.

Despite this apparent sufficiency of iodine in the waters sampled, these areas are known to have some of the highest goitre rates in the country (e.g. 44.4% for school children in Kiambu). These observations appear to advance by one step the hypothesis that factors other than simple iodine deficiency might also be instrumental in goitre development in Kenya.

THE USE OF ENVIRONMENTAL CHLORIDE AND TRITIUM TO ESTIMATE TOTAL RECHARGE TO A SAHELIAN UNCONFINED AQUIFER

Cheikh B Gaye

Département de Géologie, Faculté des Sciences, Université Cheikh Anta Diop, Sénégal

ABSTRACT

A portion of the coastal zone in the northwestern part of Senegal, underlain by an unconfined aquifer, was investigated in order to evaluate its water resources. The area was divided into three sites within which soil types were considered to have similar hydrologic properties. Mean annual recharge has been estimated using both the tritium content and the chloride concentrations of water to be from 0.5 to 34.4 mm y^{-1}, indicating a significant spatial variability. For the main research site where tritium and chloride profiles were available, good agreement was obtained between the two methods with mean annual recharge varying between 22 and 34.4 mm $year^{-1}$.

THE GROUNDWATER QUALITY SITUATION IN ETHIOPIA

Gebretsadik Eshete

Ethiopian Geological Survey, P O Box 2302, Addis Ababa, Ethiopia

ABSTRACT

Knowledge of the amount of groundwater in Ethiopia has, for a long time, been alarmingly deficient. Even more alarming is the fragmentary and scanty groundwater quality data situation. Against this background, groundwater quality aspects in Ethiopia in terms of salinity levels, high fluoride concentration etc are presented in this paper.

The presence of gypsum and rock salt is responsible for the interior quality of the groundwater in the south, south-east and north-eastern regions in Ethiopia. High concentrations of fluoride are found in the boreholes and hot springs of the Ethiopian Rift valley. Owing to excessive fluoride concentrations in the rift valley, many groundwater supply systems have had to be abandoned. In urban areas, industrial effluents and septic tanks contaminate groundwater systems. Generally, the groundwaters in the highland areas are reasonably good in quality.

PRELIMINARY INVESTIGATIONS ON THE DEFLUORIDATION OF WATER USING FIRED CLAY CHIPS

Ghirma Moges, Feleke Zewge and Martin Socher

Department of Chemistry, Addis Ababa University, P O Box 1176, Addis Ababa, Ethiopia

ABSTRACT

The adsorption of fluoride ions on ground fired clay pottery fragments has been investigated. The maximum efficiency of the adsorbent for defluoridating 1-2 litres of water was found to be 200 mg fluoride/kg adsorbent. The investigation showed that 5-20 mgl^{-1} fluoride, from 1 litre of water, could be reduced to less than 1.5 mgl^{-1} using 120-24- g of the adsorbing medium. The effects of dose of the medium, pH, contact time, and initial fluoride content were studied in relation to defluoridation efficiency. Comparison of fluoride removal capacity of the adsorbent was also made with those of fired brick, clay soil and red ash. The latter exhibited practically no adsorption. A packed column of the same ground clay pottery fragments (400 g in weight) resulted in a maximum adsorbing capacity 560 mg F^-/kg. This column defluoridated 6 litres of 10 ppm F^- in tap water to below 1.5 mgl^{-1}.

THE NATIONAL MINES, WATER, ENERGY AND GEOINFORMATION SCIENCE AND TECHNOLOGY POLICY WITH PARTICULAR EMPHASIS ON THE WATER SECTOR

Fanta Demissie

Department of Mines, Water and Energy, Ethiopian Science and Technology Commission, P O Box 2490, Addis Ababa, Ethiopia

ABSTRACT

The scientific and technological advances of recent years have revealed that the role of science and technology for national development of countries like Ethiopia is vital. In order to bring about social and technical change, to accelerate agricultural and industrial productivity, to facilitate the means for rational conservation and use of natural resources and to provide the basic necessities of life, sustained science and technology (S&T) capacity building is a fundamental requirement. In view of this, therefore, a National Science and Technology Policy has been issued recently in order to build the country's S&T capability, to coordinate related activities and to enhance their contribution to national economic development. Based on this national S&T policy, detailed sectoral S&T policies on agriculture, health, industry and mining, water, energy and geoinformation have also been issued and are being put into practice.

In this paper it is briefly discussed how the National S&T Policy and the national mines, water, energy and geoinformation S&T policies apply to the water sector. An attempt is also made to summarise the S&T situation of the water sector following the S& T capacity-building elements. Moreover, the major policy directives and strategies as well as priority programs of the water sector are highlighted. Finally, implementation of the Sectoral Policy and its implications for the water sub-sector are elaborated.

INVENTORY OF GROUNDWATER AND GEOTHERMAL RESOURCES IN ERITREA

Habteab Zerai and Tewolde Solomon
Water Resources Department, Asmara, Eritrea

ABSTRACT

Eritrea, a country situated in northeast Africa, has a coastline of 1000 km, a total area of 124320 km^2 and a population of about 3 million. The country experiences an arid to semi-humid climate with a temperature range of 20-40°C, rainfall from 200-800 mm/y and evapotranspiration in excess of 1800 mmy^{-1}.

Major basins include the Mereb and Barka rivers, and the Red Sea coast. The rivers and their tributaries are mostly seasonal and intermittent. No hydrometric records exist for the rivers within the country. Average annual discharge for Mereb-Gash at Kassala over the years 1907-1928 is 430 million m^3. The Takeze river which is on the border of Eritrea with Ethiopia has a total annual flow of 8 billion m^3.

The low and unreliable rainfall, high evapotranspiration and high sediment load of the rivers makes development of surface water supply and hydro-electricity unpromising, and therefore of little significance for the countrys economy. To avoid such problems groundwater and geothermal energy are the alternatives. In contrast to surface water, groundwater is more abundant in the country and it occurs in almost all geological formations although a satisfactory quantity and quality may not be tapped everywhere. Generally the geology of the country consists of low to high grade metamorphic rocks and associated intrusives (60%), Tertiary-Quaternary volcanics (15%) and consolidated to unconsolidated sediments (25%). The main hydrogeological units are:

- unconsolidated sediments with variable intergranular permeability
- volcanic rocks (basalts) with fracture and fissure permeability
- fissured and karstic aquifers
- metamorphic and intrusive rocks with localised low-moderate permeability along fractured and weathered zones
- aquitards, aquicludes and groundwater barriers (acid to intermediate volcanics)

Hot groundwater is available in the Red Sea coastal zone with a temperature range of 40-80°C. The water quality is good along the alluvial fans and river beds, but the quality deteriorates as one goes further towards the coast and out of the river beds. The groundwater quality in the alluvial fans and river beds decreases with the increase of depth and rate of pumping. Groundwater in the rest of the country is mainly good except in some localised swampy or marshy grounds created by the Barka and Mereb rivers.

THE SALINITY OF DJIBOUTI'S AQUIFER (REPUBLIC OF DJIBOUTI)

Ibrahim Housein and Jalludin Mohamed

ISERST, BP 486, Djibouti, Republic of Djibouti

ABSTRACT

Fresh water supplied to Djibouti town is essentially groundwater. It is located both in the aquifers of fractured Golf basalt, 1-3.4 million years old (the actually exploited zone) and Somali basalt, 3.4-9 m.y. old. About thirty wells are exploited at distances of 3 to 6 km from the sea, and provide water with relatively bad to very bad salinity (TDS between 1000 mgl^{-1} and 2800 mgl^{-1}.

A sea water interface has been recognised on piezometer Guelileh (3.8 km from the sea) at 35 metres below sea level. Furthermore, well Hidka Guisiyed, located at 11 km from the sea, presents also water with high salinity (TDS = 14028 mgl^{-1}).

The overexploitation of the aquifer and high pumping rate lead to an increase of the salinity due to the intrusion of sea water. On the other hand the chemical results do not reveal an influence of Hidka Guisiyed water in the increase of the salinity

The isotopic results of part of Djibouti aquifer (Ambouli and Nagad) show a young water, a few decades in age, with recharge due to local rain (Fontes, 1988). However, isotopic investigations need to be completed in order to have an idea of age and origin of the water in the whole aquifer.

The understanding of factors influencing the evolution of the salinity allows better management of the aquifer.

VERTICAL STRATIFICATION OF WATER QUALITY IN THE REGOLITH AND THE WEATHERED BASEMENT

John Karundu[1], Ken Howard[2] and Richard Taylor[2]

[1]Water Resources Management Department, Directorate of Water Development, PO Box 19, Entebbe, Uganda
[2]Groundwater Research Group, University of Toronto, Scarborough, Ontario, Canada MIC 1A4

ABSTRACT

In two catchments, Nyabisheki and Aroca (southwestern and northern Uganda respectively), groundwater research was carried out between 1987 and 1993 by the University of Toronto and the Directorate of Water Development, with the assistance of the IDRC.

Hydrogeological properties of the regolith and the crystalline basement bedrock have been investigated. The regolith was vertically sampled for mineralogical and hydrochemical analyses while in the fractured bedrock water from packer-tested intervals was analyzed for major ions and trace elements.

While major ions and most trace elements showed little correlation with aquifer type, Fe concentrations indicated a problem from casing corrosion at lower levels within boreholes, while Al concentrations suggested that recharge from the regolith to fractured bedrock is by no means uniform.

SURFACE AND GROUNDWATER POLLUTION IN THE CITY OF ADDIS ABABA, ETHIOPIA

Juneidi Sado

Addis Ababa Water and Sewerage Authority, P O Box 1505, Addis Ababa, Ethiopia

ABSTRACT

The city of Addis Ababa has no waste disposal facilities. Almost all industrial wastes and most domestic waste are discharge to open watercourses and storm drains, and some liquid waste is discharge via open ditches and exposed to the environment. All the industries release untreated raw waste to the environment.

Most of the streams in central and west-central Addis Ababa are heavily polluted by the waste they receive from homes, industries and large institutions.

Groundwater under the city also shows contamination mainly by NO_3. Wells in west-central Addis Ababa show high NO_3 and TDS. In central Addis Ababa (Filwoha area) wells show exceptionally high fluoride, bicarbonate and TDS. The fluoride is associated with some acidic volcanic rocks which bear the CaF_2 mineral, dissolution of which is increased in this hot spring area of the city, where temperature of the water exceeds 45°C.

The solid waste in the city poses similar problems. There is no adequate mechanism for the disposal of domestic refuse, and soil and rubble excavated from new construction sites are also not disposed of safely. Storm drains are filled up by domestic refuse and during rainy season floods cause problems on the traffic.

APPLICATION OF ENVIRONMENTAL ISOTOPES IN GROUNDWATER RECHARGE STUDIES IN A SEMI ARID FRACTURED CRYSTALLINE BASEMENT AREA OF DODOMA, TANZANIA

Hudson Nkotagu[1] and Ulf Thorweihe

SFB 69 Ackerstrasse 71-76, 13355 Berlin, Germany
[1]Permanent address: Department of Geology, University of Dar Es salaam, P O Box 35052, Dar es Salaam, Tanzania

ABSTRACT

The distribution of ^{18}O and D in various water sources indicates that groundwater recharge is due to local rainfall occurring within the basin. The stable isotopic composition of both deep and shallow groundwater is locally determined by the surficial permeability and rainfall intensity. The stable isotopic composition of rainfall is observed to be influenced more by the intensity that the absolute amount of the rainfall. The relationship between groundwater stable isotopes of hydrogen and oxygen and salinity indicates that salinisation is due to leaching of surficial and soil salts during high intensity rainfall which causes high surface runoff and flash floods. This relationship further shows presence of transpiration effects and mixing of deep groundwater at Makutapore basin. Sporadic variations in stable isotope ratios of hydrogen and oxygen, tritium values, chloride, groundwater levels and hydraulic parameters among adjacent boreholes suggest existence of a discrete fractured aquifer and/or dominance of local recharge over regional recharge from a discrete source followed by lateral flow. Groundwater recharge takes place through preferred pathways under bypass flow mechanism and diffuse flow in very permeable areas, particularly in the wadis. The strong groundwater level fluctuation with season further indicates that groundwater recharge takes place through macropores. Groundwater recharge estimates by use of environmental chloride and stable isotope abundance of hydrogen and oxygen indicate some 3% and 2% of the long-term mean annual rainfall of 550 mm forms the groundwater recharge for Makutapore and Hombolo basins respectively. It is concluded that the isotopic and chemical character of groundwater in fractured semi-arid areas could provide the most effective complementary means of groundwater recharge assessment and therefore is very useful in the management of the water resources.

APPLICATION OF PRINCIPAL COMPONENT STATISTICAL METHOD ON THE ESTABLISHMENT OF THE ORIGIN OF HIGH NITRATE GROUNDWATERS AT DODOMA, TANZANIA

Hudson Nkotagu[1] and Ulf Thorweihe

Technical University, SFB 69, Ackerstrasse 71-76, 13355 Berlin, Germany
[1] Permanent address: Geology Department, University of Dar es Salaam, PO Box 35052, Dar es Salaam, Tanzania

ABSTRACT

Principal component analysis is used for the identification of factors that bring about the chemical character of groundwater. The relationship and associations among chemical variables are established by filtering similar information patterning to them. Three factors were extracted after varimax rotation, and can significantly explain 77.2% of the total data variance.

The first factor, which accounts for about 51.0% of the variance, is highly positively loaded by Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}, HCO_3^- and EC, and is attributed to leaching of surface and soil salts along with mineral dissolution. The second factor accounts for 14.1% of the variance and is positively loaded by NO_3^- and negatively loaded by pH, and is attributed to nitrification processes taking place on sewage effluents. The third factor is highly positively loaded by $\delta^{18}O$ and δD, accounting for 12.1% of the variance, and is a consequence of evaporation processes. High salinity groundwaters are observed to be associated with high nitrate concentrations, thus implying anthropogenic sources of salts to the groundwater system. Nitrate concentrations of about 200 mgl^{-1} from both deep and shallow groundwaters are commonly encountered in the study area and are concluded to have originated from the infiltration of sewage effluents.

MOBILITY OF ARSENIC IN GROUNDWATERS FROM THE OBUASI GOLD-MINING BELT OF GHANA

Pauline L Smedley[1], W Michael Edmunds[1] and K B Pelig-Ba[2]

[1]British Geological Survey, Maclean Building, Wallingford, Oxfordshire, UK
[2]Water-Resources Research Institute, PO Box M32, Accra, Ghana

ABSTRACT

Arsenic has long been recognised as a toxin and carcinogen. A relatively high incidence of skin and internal (bladder, kidney, lung, liver and prostate) cancers has been noted in populations ingesting water with high As concentrations. Dermatological disorders (e.g. Bowen's disease, hyperkeratosis, hyperpigmentation) as well as cardiovascular, neurological, haematological and respiratory diseases are also linked to arsenic ingestion and exposure. Growing epidemiological evidence of the element's potential health risks has led WHO to decrease its recommended maximum value for As in drinking water from 50 $\mu g\ l^{-1}$ to 10 $\mu g\ l^{-1}$. This has accompanied decreases in statutory limits imposed in many developed countries.

Arsenic in drinking water from streams, shallow wells and boreholes in the Obuasi gold-mining area of Ghana ranges between <2 and 175 $\mu g\ l^{-1}$, 20% being higher than the WHO recommended maximum value. The main sources are mine pollution and natural oxidation of sulphide minerals, predominantly arsenopyrite (FeAsS). Streamwaters have been most affected by mining activity and contain some of the highest As concentrations observed. They are also of poor bacteriological quality. Some of the streams have a high As(III) content ($As(III)/As_{total} > 0.5$), probably as a result of methylation and reduction reactions mediated by bacteria and algae. Concentrations of As in groundwaters reach up to 64 $\mu g\ l^{-1}$, being highest in deeper (40-70 m) and more reducing (220-250 mV) waters. The As is thought to build up as a result of the longer residence times undergone by groundwaters in the deeper parts of the aquifer. The proportion of As present as As(III) is also higher in the deeper groundwaters.

The results indicate that streams are poor drinking-water sources as both bacteriological and As concentrations are often high. On the other hand, groundwater can form a useful potable supply of good inorganic quality provided that deep, long-residence-time sources are avoided.

CHEMICAL AND ISOTOPIC CHARACTERISTICS OF FLUIDS ALONG THE CAMEROON VOLCANIC LINE, CAMEROON

Gregory Z Tanyileke[1], Minoru Kusakabe[2] and William C Evans[3]

[1] IRGM, BP 4110, Yaounde, Cameroon
[2] Institute for the Study of the Earth's Interior, Okayama University, Japan
[3] USGS, Menlo Park, California, USA

ABSTRACT

Results of chemical and isotopic analysis of the waters and gases discharged from volcanic crater lakes and soda springs located along the Cameroon Volcanic Line (CVL) have been used to characterise and infer their genetic relationships.

Variations in the solute compositions of the waters indicate the dominant influence of silicate hydrolysis. Cationic proportions show Na^+ (40-95%) as the dominant species in the springs while $Fe^{2+}+Mg^{2+}$ (70%) dominate in the CO_2-rich lakes. HCO_3^- (90%) constitutes the principal anion in all except the coastal springs. Waters from Lakes Nyos and Monoun have Fe-Mg-Ca-HCO_3 type signatures and the soda springs essentially Na-HCO_3 type, while all other lakes have ionic compositions similar to dilute surface waters. Detectable trace elements include Mn, Sr, Ba, Li and B, and are presumed to be usually of natural origin, but the observed relatively high concentrations in some springs like Nialan (1.4 $mgkg^{-1}$ Al, 15 $mgkg^{-1}$ Sr, >0.1 $mgkg^{-1}$) are probably due to anthropogenic contamination.

Dissolved gases show essentially CO_2 (>90%), with small amounts of Ar and N_2, while CH_4 constitutes the principal component in the non-gassy lakes. Active volcanic gases are generally absent, except for the Lobe soda spring with detectable H_2S.

Stable isotopic evidence indicates the bicarbonate waters are basically of meteoric origin. The composition of CO_2 ($\delta^{13}C$ -2 to -8‰) and He ($^3He/^4He$ 1 to 5.6 R/R_a) imply a mantle contribution to the total CO_2. Methane has a biogenic source, while Ar and N_2 are essentially atmospheric in origin, though mixing is quite common.

DEFLUORIDATION OF RIFT VALLEY WATERS USING VARIOUS BONE PREPARATIONS

Zelalem Adam, Sisay Engida and Testahun Haile

Ethiopian Geological Survey, P O Box 2302, Addis Ababa, Ethiopia

ABSTRACT

A simple preparation scheme is described for the fluoride ion-removing capacity of different bone preparations using a specific ion selective electrode for fluoride ion measurement. Processed bone-meal (PBM), unprocessed bone-meal (UBM) and bone char (BC) were used for this purpose. It was observed that 20 g at 33 mesh of PBM and BC have a fluoride ion removing capacity of 10.49 and 7.50 mgg^{-1} respectively when standard fluoride solution of concentration 600 mgl^{-1} were allowed to pass through the bed at an approximate flow rate of 2 $mlmin^{-1}$. Bone char was selected for further investigation as it is economical and easy to prepare. The effects of grain size and time of contact were studied and were found to influence the efficiency of defluoridation. Defluoridation of rift valley water samples using grain sizes 12, 18 and 35 mesh of bone char demonstrated fluoride ion removing capacity of 1.20, 1.48 and 1.50 mgg^{-1} respectively. Repeated use of bone char after reactivation was also proved possible.

APPENDIX 4

Workshop on Geochemistry Applied to Water Resource Issues in Africa:

Mid-session field excursion itinerary and notes

Workshop on Geochemistry Applied to Water Resource Issues in Africa

Mid-session field excursion notes

After leaving Sodere, we retrace the route by which we came as far as Nazret (refer to Fig 1 for field excursion route). On the left, glimpses can be caught of the large (c 10 km diameter) caldera of the Gedemsa volcano. The town of Nazret (Ethiopian version of *Nazareth*) is a busy commercial centre which has sprung up in the post-war years astride the railway line from Addis Ababa to Djibouti, an important economic lifeline for the country. We now turn right onto the main highway that runs northeast up the rift valley.

The next settlement, Welenciti, is situated west of the Boseti central volcanic complex which lies on the same volcano-tectonic lineation as Sodere. Boseti has been active well into the late Quaternary and still supports some fumarolic activity. During the whole of the journey to the Awash National Park, numerous cinder cones and other evidence of recent volcanic activity can be seen.

The first stop, Kone caldera, is a prime example of such activity, and is situated on what is basically an offshoot of the same lineation as Sodere and Boseti. Formerly known in the geological literature as the Gariboldi Pass (perhaps a legacy of the road-building programme carried out under the Italian Occupation), this complex of as many as eight collapsed calderas provides one of the more spectacular clusterings of volcanism in the Eastern Rift System. The present form of the complex is largely a result of silicic cone-building episodes, between which ignimbrites were erupted and areas collapsed to form calderas, and to a lesser extent of recent basalt eruptions. In the most easily viewed part of the system, the small caldera to the east of the road, a fresh olivine-augite basalt possibly less then 200 years old can be seen covering the floor.

Soon after leaving the Kone complex, the road starts a long descent towards lake Besaka. The large central volcano of Fantale becomes visible to the northeast of the lake. Eventually the road reaches the lake, and actually passes through it on a causeway, as does the railway. Lake Besaka is apparently in hydraulic continuity with the Awash River (see the paper by Ashley and Burley in your copy of the *Groundwater Quality* book), and may owe its present increased size to the fact that since the Koka hydro-electric dam was built to the southwest of Nazret, the Awash flows at all seasons of the year. Ashley and Burley's paper also documents the fluoride problem in the groundwater of the large Metahara Sugar Estate to the southeast. The second stop will be made just before the town of Metahara, where a very recent lava flow from Fantale, perhaps contemporaneous with the late basalt at Kone, has reached the lake.

Fantale itself, which has a large caldera, is situated on the next volcano-tectonic lineation to the east of the Sodere-Boseti-Kone line. Not surprisingly in view of its recent activity, the volcano supports hydrothermal activity in the form of fumaroles and hot springs. The best examples of the latter are to the north of the volcano at Palm Springs, also known as Awash Filwoha, which unfortunately we will not be able to visit because of poor road conditions. The word *Filwoha* means "hot water" and so it sometimes crops up in connection with Sodere and other hot spring sites. The *ale* part of Fantale means "hill" in the Afar language (hence the more famous Erta Ale active volcano in northern Afar). Fantale effectively marks the boundary between the basically Christian Oromo and Muslim Afar peoples. It also marks a convenient but largely arbitrary northern limit for the Main Ethiopian Rift (MER) before it fans out into the so-called Afar Triangle. However, it is also the point where a very real change in groundwater chemistry becomes apparent, with chloride taking over from bicarbonate as the dominant anion progressively towards the centre of the Triangle, presumably as a result of Quaternary marine incursions into Afar (in contrast to the totally non-marine MER).

Next stop is the museum of the Awash National Park (the first national park in Ethiopia), where some good examples of the wildlife that can be seen in the park are preserved. The museum packs a lot into a small space and the curator is very knowledgeable about the exhibits. However, we cannot all fit into the museum at once and will therefore visit it in small groups. After this, a packed lunch will be taken at the picnic site by the Awash River. The river is as placid here as it is at Sodere, but is about to enter a more turbulent phase as it starts to cut down towards its base level, and eventual disappearance into the terminal Lake Abbe on the Ethiopia-Djibouti border.

After lunch we will see the Awash Falls, which at this time of year, *Maskaram* or "spring", should be more than usually spectacular as a result of "winter" rainfall. After a further drive through the Park, in which we should see at least some of the animals shown in the Park brochure, we shall stop at the Kereyou Lodge Hotel for refreshments (note the interesting cow-skin ceiling tiles). The hotel is perched on the side of the deep gorge now occupied by the Awash. Evidence of numerous lava flows can be seen in the walls of the gorge. A little further downstream is the settlement of Awash Station, where the railway crosses the river on the way to Dire Dawa and Djibouti.

The return journey will take place along the same main road, which like the railway is an important commercial artery. Time permitting, a stop for refreshments will be made at a hotel in Nazret, where many of the boreholes yield warm water with a high fluoride content and potable water has to be obtained from boreholes some km to the southwest of the town. On the drive back from Nazret, the Sodere rhyolite block should be highlighted by the afternoon sun. Beyond, the well-defined eastern wall of the rift valley can be seen. This contrasts with the poorly-defined western wall in this north-central part of the MER.

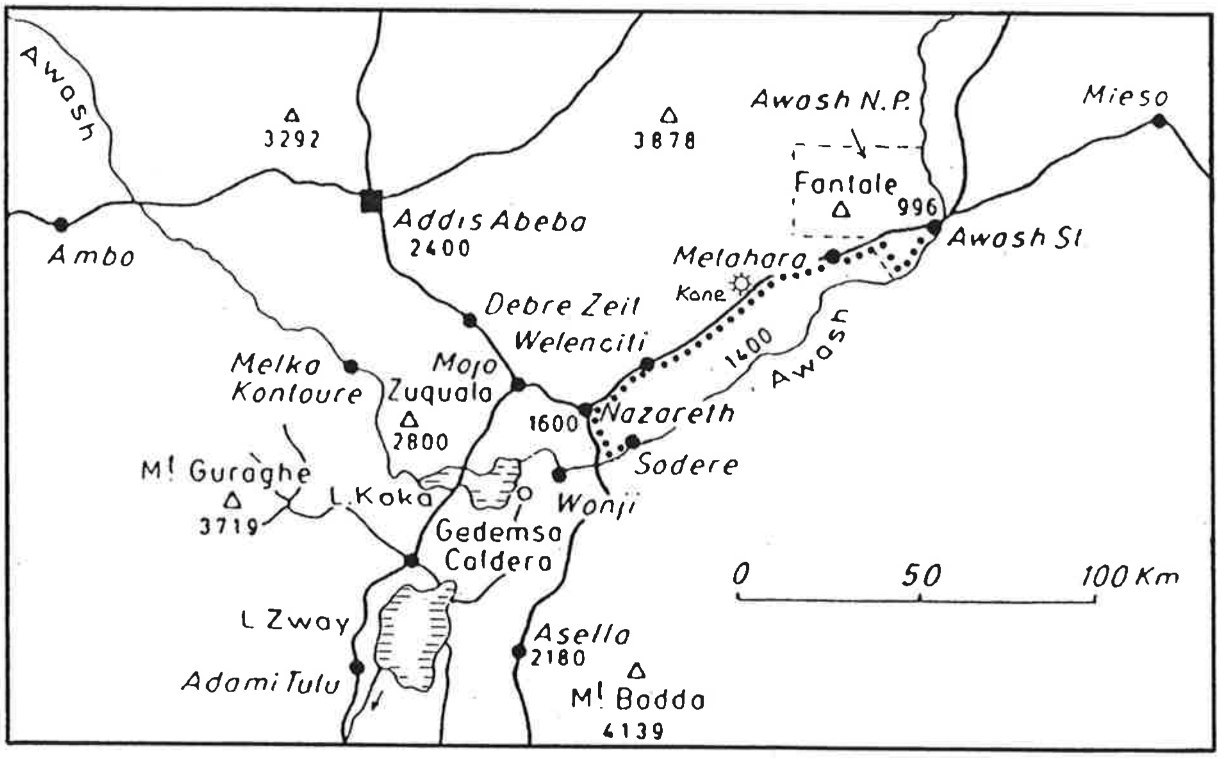

Fig 1 Route of the mid-session field excursion to the Awash National Park

APPENDIX 5

Workshop on Geochemistry Applied to Water Resource Issues in Africa:

Framework for water quality studies in sub-Saharan Africa

Geochemistry Applied to Water Resources Issues in Africa

25-30th September 1995, Sodere, Ethiopia

FRAMEWORK FOR WATER QUALITY STUDIES IN SUB-SAHARAN AFRICA

A. Areas of future research application of particular relevance to African countries

Better recharge estimation

Many studies proceed without adequate understanding or quantification of the water balance. The consequences can be seen widely in falling water levels and evidence that water may be being mined. Classical water-balance methods often fail in semi-arid regions, making geochemistry of special value via techniques such as conservative tracing, particularly using porewater chloride, which can be used to determine direct recharge through soils and to determine spatial variability in soil hydraulic conditions. There is therefore a need to create laboratories that can determine Cl (and other parameters) with the necessary precision at low concentrations. Additional collection stations should be established to create a wider network for the measurement of precipitation amount and chemistry for the better evaluation of recharge.

Water-quality stratification and well construction

Improved databases and knowledge of variations in water quality with depth as well as laterally are needed. It is common practice to construct wells to a standard specification based solely on yield. From discussions and data presented at the Workshop, it is clear that some preliminary hydrogeophysical logging for SEC-T and/or depth sampling should be carried out in well construction programmes. This is essential to assess natural hazards (e.g. high fluoride) or the extent of anthropogenic pollution so that, where possible, the design of wells is optimised together with physical parameters. It is noted that pumped samples will inevitably be mixtures of water from different depths.

Water quality monitoring

Improved assessments of water quality require the introduction of monitoring to ascertain temporal trends, particularly in respect of anthropogenic pollutants. At present few countries in Africa have monitoring programmes. Rapid development of scarce water resources requires that regular programmes be set up for both quantity (water level) and quality (basic indicators of environmental impact). This can be done inexpensively by measuring selected indicators such as Cl, NO_3, HCO_3 and TOC which act as proxies for complex processes such as urbanisation.

Baseline conditions

Chemical constituents of water such as F, I, Fe and As may build up as a result of natural geochemical processes, and require geochemical understanding to alleviate the problem in vulnerable area. Improved datasets on these key elements and their regional distribution are needed.

Salinity/salinisation

Geochemical methods can be used to differentiate saline waters of various natural origins (sea water, evaporite-derived, ancient formation water etc) using a number of techniques (isotopes of water, Mg/Ca, Br/Cl etc). Salinisation, which is man-induced, can also be followed using O and H isotopes together with measurements of SEC and chloride.

Pollution (urban, landfill, mining, sewage)

This is a large area of paramount concern which in detail is beyond the scope of this workshop. Geochemical processes which can be observed in natural systems are also of relevance in polluted aquifers (e.g. redox controls) and may be important in controlling the incoming pollution. Careful monitoring is needed at the limits of areas of known or suspected pollution in order to be able to detect early signs of change in the water quality. It is stressed that simple, mobile indicators such as Cl, HCO_3 and NO_3 may be sufficient to detect pollution and to define the pollution plume, on which more detailed work can be done if necessary.

Energy-related problems (atmospheric pollution, geothermal)

In Africa problems such as sulphur and nitrogen oxide emissions with the resulting acid rain are likely to be only local problems associated with power generation and specific industries. Nevertheless, rainfall sampling as part of an environmental monitoring strategy is to be encouraged. In several East African countries geothermal development can benefit from geochemical studies at the exploration, evaluation and exploitation stages.

Water treatment and remediation

The high cost of water treatment and limited availability of water resources suggest that there may be some benefit in instigation of dual-quality supply systems, where only sufficient water for drinking-water needs is purified to potable standards. This could be a solution to the fluoride problem, for example.

Priorities in hydrochemical analysis

Facilities for analysis of waters may be rather limited and some priorities are stressed:

1. Priority to be given to major ion analysis (Ca, Mg, Na, K, Cl, SO_4, HCO_3 NO_3) and emphasis placed on ionic balance as a check of accuracy.

2. Measurement of chloride as an inert natural tracer is important to gain information on physical parameters such as recharge and mixing.

3. Very high analytical precision for the above should be aimed for. This is important in monitoring studies since slight variations in ionic concentrations or ratios can be indicative of changes in water quality.

4. For geothermal resource studies Al, Li, B and SiO_2 are of diagnostic value in addition to the F and Fe already identified for baseline studies in general, and need to be included in the scheme of analysis.

5. Isotope techniques are of great value in hydrogeological studies in Africa. There is a need for the establishment of one or more well-equipped and versatile isotope laboratories

for the sub-Saharan African countries.

Modified approaches:

1. All priority areas would benefit from **improved databasing,** involving the need for investment in software, hardware and instigation of legislation to ensure geological/geochemical data are stored in a central accessible place and preferably that software is standardised across institutes.

2. **Better research-program design**: adoption of simple techniques to investigate processes and pathways to make best use of limited resources.

3. **Geochemical modelling**: increased use and awareness of geochemical models as techniques for testing geochemical hypotheses.

4. **Interdisciplinary cooperation:** future programs should be broadened to incorporate interdisciplinary approaches e.g. geochemistry/epidemiology collaboration in health-related water-quality problems (especially in relation to F problems), agronomy in agricultural problems.

B. Policy

Water acceptability and health issues

It is recommended that (interim?) threshold limits for drinking water be adopted which are realistic for each African country. Standards which are laid down for developed countries may be inappropriate for countries where the baseline conditions are different in terms of salinity and related ions. For example, naturally high nitrate may occur in semi-arid countries in water (e.g. palaeowater) of otherwise high quality (i.e. free of pathogens) which may be the main source of available water. It is recommended that freedom from harmful organisms be treated as the highest priority *pro tem*, since this is usually the main source of ill-health. There is a need for better liaison between water resources and health personnel to anticipate hazards before they become serious and necessitate expensive treatment.

Protection of shallow wells

Proper well construction is a high priority and monitoring of quality combined with good public health education is essential.

Siting of wells based on water-quality data

Geochemistry has a potentially important role to play in designing borehole-drilling strategies to obtain water of good potable quality, but is rarely incorporated into rural water-supply programmes. NGOs need to be made aware of the lateral and vertical variations in water quality likely to be encountered in areas highlighted for borehole emplacement, before boreholes are completed.

Establishment of protection zones

All water supplies need protection. The factors that lead to contamination need to be considered in order to recognise adverse signs of water quality. For example, siting of wells upstream should be adopted. As stated above, simple measurements of mobile ions such as chloride can often herald change.

Legislation

In many African countries new or increased legislation is required to improve the quality of water supplies. Such legislation needs to control both the routine monitoring and registration/databasing aspects of water quality and quantity data. Public ownership of all important data on groundwater is to be encouraged.

Training

Training is identified as a high priority area to develop local and in-house expertise, reduce dependence on donor countries for instrument maintenance, and to ensure continuity of capable technical staff. Inter-country training/education exchange programs should be pursued and encouraged. Databases of technical and research expertise in each African country should be set up to ascertain both centres of excellence in research fields and to identify areas of need. UNESCO could be approached for establishment of regular sponsorship to cover training and exchange needs.

Investment/consolidation

More investment in imported analytical equipment is needed. There is also the requirement for donor countries to follow up investment programs for effective long-term use of durable equipment. At the same time, it is also necessary to promote local African manufacturers of instrumentation for monitoring.

Instigation of research networks

Research progress would benefit from instigation of expert networks for inter-country exchange and development of research ideas, analytical and other facilities and training. Communication to this end could be facilitated by fax, e-mail, newsletters and workshops. Constitution of a steering committee to keep up with international research developments would also aid progress.

Dissemination of information

A high priority should be given to dissemination of practical research findings, particularly to NGOs, water users and policy makers. Scientific information should be communicated to the public in a simple and understandable way.

Second Geochemistry Workshop (ca. 1998)

During the Workshop, interest was expressed in development of a triennial workshop addressing progress in water-related geochemical research in Africa. South Africa and Zimbabwe were nominated as possible host countries for a second workshop. Sponsorship would be required for the event, potential sponsors including the British Council and their French equivalent (Alliance Française).