*Groundwater and Climate in Africa* (Proceedings of the Kampala Conference, June 2008)
IAHS Publ. 334, 2009.

# Monitoring groundwater resources in Sub-Saharan Africa: issues and challenges

**S. M. A. ADELANA**
*Department of Geology, University of Ilorin, Ilorin, Nigeria*
sadelana@gmail.com

**Abstract** Over the last five decades the growing demand for freshwater has created water shortages in many parts of the world. Reliable assessment of groundwater resources, required to supply rapidly growing populations in Africa under a changing climate, places extraordinary demands upon the field of hydrogeology. The limited knowledge of groundwater resources on a national scale hampers development and managed use of this resource in many countries of Africa. Effective management of Africa's groundwater resources is therefore challenging under these conditions and requires improved monitoring of groundwater resources. While new solutions are needed to meet future water demands globally, critical shortfalls exist in Africa of sustained monitoring of basic hydrogeological parameters. This paper reflects on the shortfalls in the designs, construction and maintenance of groundwater databases and presents case studies that employ monitoring data with current challenges in modelling groundwater use in Africa. Prior to identifying possible strategies and cost-effective techniques for groundwater monitoring, cognizance of constraints and considerations such as responsibility and funding is considered in this study. Proposed strategies consider the level of information required at country- and continent-scale, available resources, monitoring frequencies, funding and the use of a pilot-scale study to initiate national or continent-wide monitoring networks.

**Key words** groundwater database; resource monitoring; groundwater management; Sub-Saharan Africa

## INTRODUCTION

Groundwater supplies over 70% of Africa's water supply systems; both economic development and poverty reduction imperatives drive the development of groundwater resources across Africa (Adelana & MacDonald, 2008). Groundwater has long been considered a reliable and readily adaptable source for rural water supplies. This has contributed, in part, to the heavy reliance upon groundwater for rural water needs. In Africa many cities where there has been considerable dependence upon surface-water reservoirs, are augmenting or planning to augment their water supplies with groundwater-fed systems due to increasing demand and deteriorating quality of surface water. Indeed, growing demand for freshwater is creating water shortages in many parts of the world, Africa included. Reliable assessments of groundwater resources, required to supply rapidly growing populations in Africa under a changing climate, places extraordinary demands upon the field of hydrogeology. Limited knowledge of groundwater resources on a national scale hinders development and the managed use of this resource in many countries of Africa. Effective management of Africa's groundwater resources is therefore challenging and requires a reliable groundwater monitoring network. This paper reflects on the shortfalls in the designs, construction and maintenance of groundwater monitoring networks and considers model case studies that employ monitoring data. The approach adopted is to review the factors preventing availability of basic hydrogeological data, the underlying technical concepts, and necessary steps to ensure effective and continuous data monitoring.

## BASIC GEOLOGICAL AND HYDROGEOLOGICAL BACKGROUND

Most of Africa is a series of stable, ancient plateaux, low in the north and west and higher (rising to more than 1830 m) in the south and east. The plateaux comprise mainly of metamorphic rocks that have been overlain in places by sedimentary rocks. Most of Sub-Saharan Africa (SSA) is characterized by low relief, high evapotranspiration and low groundwater baseflow and recharge (Wright, 1992). The geology and hydrogeology are also highly variable: 34% of Africa comprises heterogeneous Precambrian basement; 37% consolidated sedimentary rocks; 25% unconsolidated sediments, and 4% volcanic rocks (MacDonald *et al.*, 2008). Some rocks form highly productive aquifers. The large sedimentary basins of North Africa with high storage and transmissivity permit high yielding boreholes to be constructed. In many other regions, less weathered Precambrian basement and mudstones are poorly yielding and groundwater may be difficult to find, or in some places non-existent.

Water supplies in rural and urban areas in SSA based on groundwater derive from several aquifers. Major aquifers occur in the African platform and in the folded zones. About 42% of the area of the African continent is underlain by relatively homogeneous aquifers and 8% by groundwater in geologically complex regions. Almost 50% of Africa shows only local and shallow occurrences of groundwater that are generally restricted to unconsolidated rocks near the surface (Foster, 1984; Wright & Burgess, 1992; Macdonald & Davies, 2000). A useful summary of the hydrogeology of sub-Saharan Africa is given in MacDonald *et al.* (2008). The most important aquifer systems in sub-Saharan Africa exist in the weathered crystalline rocks, which are discrete, mostly fractured bedrocks extending across and underlying much of the land surfaces (Fig. 1). The weathering products of these crystalline basement rocks form a shallow but low-productive aquifer, which provide a vital source of water-supply for the rural population of Africa and livestock (Foster *et al.*, 2000).

A map of groundwater resources of Africa has been demarcated and published with the groundwater resources of the world on a scale of 1:50 000 000 (WHYMAP, 2007, available on: www.whymap.org). This shows that the conditions of the groundwater environment vary from region to region and reflects the recharge characteristics of the various aquifers. It also shows that most of the groundwater areas in Africa cross political borders, forming shared trans-boundary aquifers. Aquifers can be complex, often with lenses of sand, gravel and silts, depending on the depositional environment. Flood plains of big rivers like the Zambezi, and the inland Okavango Delta in Botswana are typical examples of this (Carter & Bevan, 2008). The major volcanic area is concentrated in East Africa in a wide band across Ethiopia and Kenya. This is formed predominantly of lava flows and basalt sheets that were associated with the opening of the Rift Valley system (Foster, 1984). These volcanic rocks can be jointed and fractured, have weathered areas, and are interleaved with ash layers and palaeosoils, which are often porous forming prolific aquifers. The variation of water well characteristics with terrain and yield of wells are illustrated in Foster *et al.* (2008).

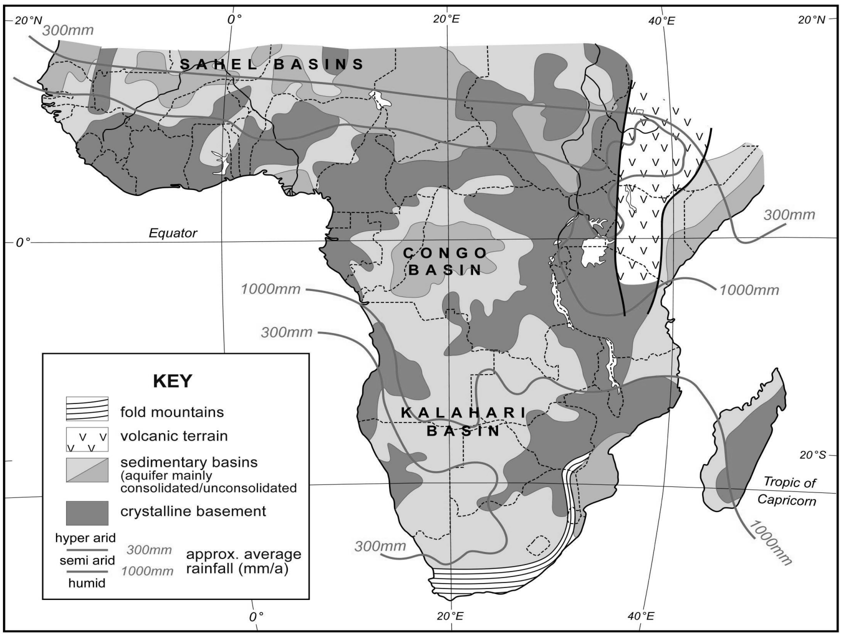

**Fig. 1** Simplified geological map of Sub-Saharan Africa (Foster *et al.*, 2008).

## GROUNDWATER RESOURCE ASSESSMENT AND MANAGEMENT

Africa's hydrogeology has been summarized at regional levels (Jones, 1985; Macdonald & Davies, 2000; Davies & Cobbing, 2002; Zektser & Everett, 2004; Davies, 2005; MacDonald *et al.*, 2005, 2008). However, detailed information on groundwater and its behaviour is lacking for many areas of Africa, and it is difficult to provide quantitative assessments of the continent's groundwater resources. One of the prerequisites for the rational groundwater management and exploitation is defining quantity and quality of water resources.

Unrestricted use of groundwater through tube wells and boreholes utilizing technological advances has resulted in lowering of the water table in many urban and rural areas of SSA (Foster *et al.*, 2008). Often urban groundwater use can lead to over-exploitation and consequent problems such as saline water intrusion and encroachment inland. Examples include the south coast of Lagos, Dakar, and Cape Town (Adelana *et al.*, 2008). Thus, groundwater quality is often worse beneath cities than beneath nearby rural areas. Therefore, optimal utilisation and management of groundwater resources will require improved capacity to assess groundwater potential and monitor trends, with a better understanding of aquifer functioning. The key challenge in SSA is developing capacity to manage and monitor intensive groundwater use. Appropriate technology and sustainable financing are also critical management constraints.

Groundwater management practices vary from country to country within the continent of Africa, and in some cases, do not exist at all. This is a long-standing problem in SSA and, as such, requires a framework of collaboration on groundwater studies. Such collaborative efforts should focus on providing the basic geological and groundwater data essential to manage groundwater resources across the continent. In SSA, there is a need to identify what information is essential to an understanding of the complexity of the various groundwater resource systems, their accessibility and sustainability. For example, over pumping and low recharge have led to water tables falling below pump levels in northeastern Botswana (Robins *et al.*, 2002). Similar problems are reported to have affected boreholes in the Afram Plains in Ghana, where boreholes are drilled along apparently high yielding fractures, with no effort made to understand the nature of the fracture systems or their extent (Robins *et al.*, 2002). Both examples make a compelling case for recording data and observations during the drilling programme.

Current legal and organisational frameworks for groundwater management within SSA are fragmented, inconsistent and sometimes incomplete. It is also obvious that the decentralization of water resources management, partly driven by donor pressure (Ockelford & Reed, 2002) to non-government organisations (NGOs) has affected data collection and ultimately that which is usable for groundwater management (Robins *et al.*, 2006). Although laudable in approach, it brought about a rapid fragmentation of interests and the long-standing institutional knowledge base, as well as a noticeable collapse of record keeping and data gathering in many countries of the region (Calow *et al.*, 2002). All of these needs to be changed to ensure that data gathering are again perceived by governments, NGOs and Aid Agencies to be an important component of any water programme.

## CURRENT CHALLENGES IN MODELLING GROUNDWATER USE IN AFRICA

There is a growing use of groundwater in Africa for both rural and urban water supply. Large cities that are groundwater-dependent in SSA are shown in Fig. 2 (Adelana *et al.*, 2008). Recent development and increased groundwater demand will add more cities to this list. In cities where groundwater is a small fraction of total water use, it still represents a stable source of water, when and where surface water resources may fluctuate. Rural settlements, on the other hand, are nearly all dependent on groundwater for safe drinking water supply. This growing dependence on groundwater calls for increased attention to groundwater development and careful management of the resource, thus requiring a well-structured monitoring programme in SSA.

In Africa, there has been a gross inadequacy of hydrogeological data and research into the understanding of groundwater resources, renewability, apportionment and management. Data

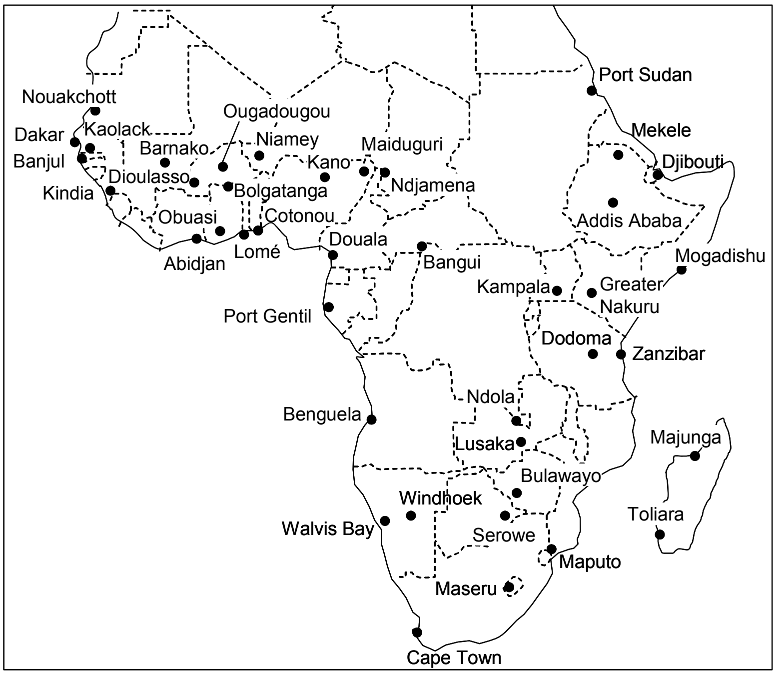

**Fig. 2** Examples of cities dependent on groundwater in Sub-Saharan Africa (Adelana *et al.*, 2008).

gathering and dissemination are fundamental to the development and management of the resources in any country. However, significant concerns have emerged over the lack of basic data gathering and collation on groundwater resources in SSA (WB, 2005; Robins *et al.*, 2006), pointing to an urgent need for increased funding in resource management and, subsequently, monitoring programmes. Whilst South Africa has put in place a functional National Groundwater Database and developed a groundwater quality monitoring programme, several other countries have neither the resources nor the capacity to do likewise. Some effort, however, is now directed towards recognising knowledge gaps and coordinating data and understanding between groundwater dependent nations, principally under the auspices of the SADC (SADC, 2002; Farr *et al.*, 2005). An ongoing challenge in water resources management in Africa is quantification of groundwater resources. In the past, failure to record or archive critical data sets (drilling logs, pumping tests) has resulted because those engaged in groundwater development are either unaware of the value of these data sets or unable to record them. Hydrogeologists thus have a critical role to play in assisting the development and maintaining of national groundwater databases.

Other challenges include definition of measured parameters and unifying modes of data collection and central collation, especially where differences in aquifer characteristics and level of usability of aquifers exist. Modelling groundwater management scenarios suffers from a paucity of reliable data with which to calibrate and validate numerical models. Indeed, there is an urgent need to arrest the loss of data and to recover the amassed information. Faced with the declining loss of expertise in some countries, there is an intense opportunity for capacity building and training of African hydrogeologists. Both the Burdon Network of the International Association of Hydrogeologists, and coordinated projects funded by organisations such as the German Federal Ministry of Water Resources, seek to address this situation, but further efforts are required. Another crucial issue in groundwater management is ownership of groundwater. Where there is no ownership it may be difficult to apportion monitoring and management responsibilities to government or agencies. For example, groundwater in South Africa is owned by the nation and managed by the Department of Water Affairs & Forestry (DWAF). The DWAF was then charged with the responsibility of monitoring both groundwater quality and quantity.

Ignoring either technical or social factors can compromise the sustainability of urban and rural water supplies. If communities do not regard the system as theirs, and managing and cost-sharing arrangements are not adequately dealt with, the system is more likely to fail. If a well or borehole is poorly constructed, or developed, and sited with little regard to the geology, the chances of mechanical breakdown or the source drying up increase. In addition, there are many countries in SSA where governments have divested groundwater resources data gathering and collation to projects through the NGOs and consultants so that data are neither being collected in the field nor collated. Where local wellfield monitoring is undertaken by private companies, water utilities, or as part of specific projects, few data currently reach the national groundwater authority. For example, there is presently no collection of time series hydrogeologic data of any type in the Democratic Republic of Congo (Robins *et al.*, 2002), in Nigeria and Zambia (Adelana *et al.*, 2008). Although the government of Malawi is now investing into groundwater data gathering, lots of gaps exist and there is a long way ahead.

Changes in development aid emphasis and funding policies have also impacted on groundwater resource development. International donors have, in general, had limited involvement in the technical and engineering aspects of groundwater resource development, preferring to concentrate on socio-economic planning and policy development as well as the "soft" side of agriculture, health and education (MacDonald *et al.*, 2005). This has resulted in a significant increase in the use of donor-funded contractors and consultants in the regional water sector with a consequent marked decline in knowledge accrued by national government institutions (Robins *et al.*, 2003). In the international donor community, the Japan International Cooperation Agency (JICA) is one of few international donors still directly involved in the groundwater sector and is currently active in Zimbabwe, Zambia and Tanzania (JICA, 2002). Although many thousands of boreholes are drilled each year in sub-Saharan Africa, established systems for gathering and collating this information commonly fail. Abandonment of data collection is a recurrent issue and collection of basic data is often compromised due to the emphasis placed upon water provision at low cost, coupled with a focus on sociological evaluation, both of which tend to lessen the perceived importance of hydrogeology (Robins *et al.*, 2002).

## DESIGNING AND MAINTENANCE OF GROUNDWATER DATABASES

The scope and details of the available data have dictated the level of groundwater information and research in Africa. The design of a groundwater monitoring programme should be based on clear and well thought out aims and objectives to ensure that planned monitoring activities are feasible. It is not enough to prepare a monitoring programme document with a clear statement of the objectives. Area descriptions and geographical limits of the area monitored are also crucial. Sustained monitoring of hydrogeological parameters and groundwater quality should be ensured rather than ad hoc, short-term project-oriented data collection. In the real sense, no monitoring programme should be started without critically scrutinizing the needs for groundwater information. Consequently, preliminary surveys may be necessary in order to determine the focus of the operational programme. For example, monitoring and assessment of groundwater quality are based upon the fundamental physical, chemical and biological properties of groundwater. Yet water quality monitoring and assessment is a process of analysis, interpretation and communication of those properties within the wider context of human activities and use, and the conservation of the natural environment (Bartram & Balance, 1996). The present and past water uses as well as the status and expected pollution sources should be identified.

Strategies employed in Europe and the United States to establish large-scale groundwater monitoring networks and groundwater protection programmes could serve as a good example in establishing the African network. However, looking at resources available, a strategy for initiating monitoring in priority areas may be a better starting point. The monitoring programme can then be extended to other areas as more resources become available. This may necessitate the use of information tools that could facilitate the definition of priority areas: (1) published national groundwater-use maps per individual country, (2) country-by-country level aquifer vulnerability maps, (3) national or regional hydrogeological maps. A practical approach to overcome the problem of defining priority areas/regions would be to prioritise on the basis of cities or regions currently using groundwater for domestic, industrial and agricultural supplies. The following, as set out in the legislation of South Africa, provide a case example on groundwater monitoring.

## THE SOUTH AFRICAN GROUNDWATER MONITORING AND NATIONAL GROUNDWATER DATABASE: LEGAL FRAMEWORK

The legal framework for the provision of water services under the South African Water Act for water and local government sectors has been finalized (Vermeulen, 2002) and it stipulates how groundwater should be monitored.

(a) Abstraction: The South African National Water Act (1998) sets the framework for Catchment Management Agency (CMA) to stipulate that groundwater abstraction and quality be monitored. Currently all users that abstract more than 10 $m^3$ of water per day from one or more boreholes are required to register this water use and obtain an abstraction license (DWAF, 2000).

(b) Groundwater level monitoring: The South African Department of Water Affairs and Forestry (DWAF) set out the Minimum Standards and Guideline for Groundwater Resource Development for the Community Water Supply and Sanitation Programme in 1997, which stipulates a borehole should be fitted with a piezometer tube (section 4), and it stipulates the extent of groundwater monitoring training that should be provided (section 5). The National Water Act (1998) specifies that national monitoring systems on water resources must be established with the purpose of assessing the quantity of water in the various water resources and ensuring compliance with resource quality objectives. The implication of this is that groundwater levels need to be monitored, but the Act is not specific on monitoring requirements.

(c) The Compulsory National Standards (section 9(1)) published as a Government Notice (no. 22355) on 8 June 2001 stipulates that all Water Service Authorities (WSA) must have a programme for sampling the quality of supplied water, and this should be included in the Water Services Development Plan of the WSA. This regulation tends to leave out sampling of groundwater prior to conveyance and storage. Fortunately, the license agreement under the National Water Act (1998) contains conditions regarding water quality monitoring at the boreholes.

### DWAF’S vision for groundwater monitoring

The South African legislative framework is clear but the practical realities of implementation are more complex. The current status of water services provision has loopholes. There are sometimes long delays in the transfer of DWAF-implemented water projects to the responsible Water Service Authorities. DWAF has a good programme in place for transferring schemes, but the procedure can be delayed. A similar situation exists for water projects implemented through other implementing agents and non-governmental organizations. Moreover, uncertainty in ownership and Operation and Maintenance (O&M) responsibilities in the area of water services provision to rural communities has contributed towards little effective O&M management and even less to groundwater management. The free basic water policy operated under South African law has also complicated the management issue, particularly for community-operated schemes where knowledge of free basic water appears to have contributed to non-payment and the subsequent disuse of schemes. Nevertheless, DWAF is committed to the vision of groundwater monitoring. There are four “types” of groundwater monitoring recognized by the DWAF (Table 1) based on the monitoring guidelines of the UN/ECE Task Force on Monitoring & Assessment (2000), defined according to the purpose of monitoring.

### Summary of groundwater data needs for resource management

As set out in the framework for groundwater management (DWAF, 2004), particularly managing groundwater in rural water supply schemes in South Africa, groundwater management has been

**Table 1** DWAF's groundwater monitoring types (simplified).

| Reference no. | Type | Objectives | Purpose |
|---|---|---|---|
| 1 | Reference (natural conditions) | To establish the background (reference) situation | To determine, for example:<br>– the status of natural conditions (conditions not impacted by humans)<br>– natural groundwater behaviour and long–term trends<br>– the relationship between surface and groundwater. |
| 2 | Regulatory monitoring (compliance) | To monitor authorized activities that affects groundwater, e.g. groundwater usage, waste management, potential polluting activities, etc. | To determine the impact of anthropogenic activities on groundwater, and to control these activities according to management objectives and regulations (such as license conditions). |
| 3 | Specific purpose monitoring | To meet specific objectives not covered in Types 1, 2 and 4. | To meet particular objectives, e.g:<br>– to research specific aspects of groundwater flow or chemistry;<br>– to establish surface–groundwater interactions (not under Type 1 conditions)<br>– to fill in data gap needed for modelling, monitoring contaminant plumes, determining water balances, etc. |
| 4 | Early warning and surveillance | To provide information for an emergency response. | To obtain information, for example, where an accidental pollution spill may affect a drinking water supply. |

grouped into five main areas: (i) fulfilling legal obligations (i.e. ensuring use and protection of groundwater according to national and international laws), (ii) monitoring and analysing data (e.g. groundwater levels and abstraction), (iii) optimizing groundwater usage, (iv) protecting groundwater from contamination, and (v) creating awareness and educating people about sustainable groundwater use.

Besides the basic borehole information such as location, depth, diameter, etc., the following data should be recorded on a regular basis: (i) borehole water levels, (ii) groundwater abstraction rate, (iii) groundwater quality, (iv) potential pollutants, and (v) rainfall at every production borehole for adequate correlation with water level. The frequency of water level monitoring needs to be assigned on a borehole-by-borehole basis, by a person with relevant skills or experience, and should be done at best on a monthly basis. More frequent monitoring is recommended if it is suspected that water level is being drawn down to the pump inlet on a regular basis.

A possible way of establishing the necessary frequency of water level monitoring would be to install automated, electronic data loggers ("divers") in the boreholes for a limited period (say, a few days to a few weeks), until the effect of abstraction has been established. By reviewing this data, it would be possible to optimize the pumping rate and pumping cycle, and recommend a monitoring programme. The generic guidelines for sampling frequency of groundwater quality monitoring are provided in *Quality of Domestic Water Supplies*, volume 2: *Sampling Guide* (DWAF, 2000). This includes the sampling frequency for chemical sampling, sampling frequency for microbiological sampling, design of sampling programmes and detailed sampling guides. Figure 3 shows the principal tasks of groundwater management in the context of community water supply (DWAF, 2004).

## CASE STUDIES THAT EMPLOY MONITORING DATA

This section reflects on the effects on the shortfalls in groundwater databases or on the outright lack of a database as presented in the case studies that employ monitoring data in an attempt to model groundwater flow and interactions in parts of Africa. These cases are known to have been initially developed and/or used intensively in response to urban water emergencies involving a reasonable-sized population served with groundwater, and are summarized in Table 2.

**Table 2** Selected case studies with data on groundwater use & modelling approach in Sub-Saharan African cities*.

| Case City | Addis Ababa (Ethiopia) | Abidjan (Cote D'Ivoire) | Cape Town (South Africa) | Dakar (Senegal) | Lagos (Nigeria) | Lusaka (Zambia) |
|---|---|---|---|---|---|---|
| Location in SSA | Inland (East) | Coast (West) | Coast (Southernmost) | Coast (Northwest) | Coast (West) | Inland (Southern) |
| Population ($\times 10^6$) | 4 | 3.7 | 3.48 | 2.45 | 14 | 1.8 |
| Average rainfall | 1150 mm/year | 1600 mm/year | 600 mm/year | 485 mm/year | 1700 mm/year | 900 mm/year |
| Geology | Volcanic materials of different ages | Coastal sedimentary (Cretaceous – Quaternary) | Cenozoic sands underlain by phyllitic shale, quartz schist; Cape granite and sandstone | Coastal sands with marly limestones | stratified sedimentary rocks (silt, clay) with peat or coal | Schists interbedded with quartzites; dolomites and limestones |
| Water level data (well) | Fairly good but no database | Shallow, not well documented | Fairly good record since 1967 but lots of gaps | Record since 1975 with missing gaps | Shallow, no consistent data | Shallow, fragmented data |
| GW Information[#] status | 1 | 2 | 1 | 2 | 2 | 3 |
| Estimated GW level decline | ? | ? | Limited use, unquantified abstraction from wellpoints | ? | Appreciable but data record | 30 m (1985–1995) |
| Main aquifer type | Multilayer volcanic rocks mainly composed of acidic and basic rocks | Unconfined aquifer existing in Quaternary deposits: marine sands (Nouak-chottien) and fine sands (Oogolien) | Thin – thick unconfined sand (semi-confined in places), Fractured sandstone (TMG) aquifer | Two aquifer systems: semi-confined and unconfined with thickness varying from 50–80 m from E–W | Thick sand and overburden/superficial deposits with deep confined sands | Unconfined differentially Karstified marble aquifer |
| Aquifer storage | Small in the northern and central part of the city and very high in the eastern and southern part of the city | Moderately large with progressive degradation of the quality from the south towards north and west | Moderately large but towards margins increasing salinity | Small with increasing salinity from the NE towards the NW. | Moderate with increasing salinity towards the west margins | na |
| GW use (Ml/d) | 70 | ? | 50 | 73 | ? | 200 |
| Source of primary recharge | Rainfall and dams | Mainly rainfall but mixing between the waters of different recharge episodes within the aquifer exist | Mainly rainfall, periodic infiltration of runoff | Mainly rainfall | Excess of rainfall, canal and riverbed infiltration | Mainly rainfall, but with a substantial contribution from water utility supply and sewer leakage |
| Pumping wells (wellfield) | 520 km$^2$ | Not estimated | 550–700 (630 km$^2$) | 300 km$^2$ | >2000 (3600 km$^2$) | Current estimate exceeding 5000 |
| Aquifer depletion | There is potential depletion in the southern part of the city | Not currently quantified but modelling projection shows 0.33 m/year | - | 0.133 m/year (from model calculation) | Few data, probably averaging 0.5 m/a | Currently, not quantified |
| Model approach | ? | Groundwater flows modelling to quantify the groundwater resources* | Modelling groundwater behaviour | Investigate impact of withdrawal and seawater advancement** | Numerical groundwater flow modelling | - |
| Limitations | ? | Calibration by "grouping" because of insufficiency of piezometric data | Limited monitoring data | Few head data for calibration and to evaluate impact of seawater | Validity of assumptions; no computerized database | - |
| Sea water encroachment into aquifer | | ? | 0.6 km inland from the coast | - | ? | - |

* This table was prepared with information from Adelana *et al.* (2008), Foster *et al.* (2008), Kouame *et al.* (2008) and valuable inputs from colleagues whose efforts are gratefully acknowledged.

[#] GW Information: 1 represents Full survey data, 2 represents Useful summary document, 3 represents General background only.

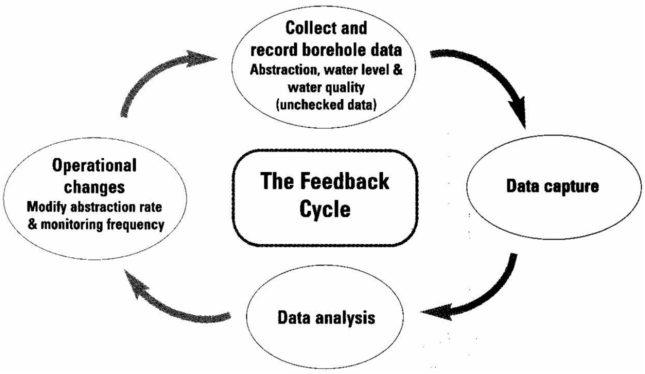

**Fig. 3** The principal tasks of groundwater management.

## STRATEGIES FOR EFFECTIVE DATA MONITORING

At the national scale, water-related issues are generally governed through the respective countries water authorities. Whether this holds true for groundwater and in all countries in Africa is a question that still needs to be answered. Knowledge concerning the spatial distribution of groundwater and groundwater quality data across the countries is still very sparse. Although some recent progress has been recorded in this regard in many countries, there are shortfalls preventing effective research programmes. Evaluation of the resource requires regional survey and conventional determination of the water balance.

In SSA, the need to assess the resource potential is not universal. This study has not focused on all of the technical aspects that need to be considered in the design of a monitoring network. Looking at previous work (e.g. Parsons & Tredoux, 1995; Robins *et al.*, 2002), four components are nonetheless important as they play an important role in defining network-resource requirements. They are: (1) determination of the number of monitoring stations that are required to meet monitoring objectives; (2) use of existing boreholes; (3) measurement or sampling protocol to define frequency and prescribe mode of measurements; and (4) selection of monitoring tools (equipment). Establishing a representative monitoring network is not an easy task. The network should start at a simple, unsophisticated level and then work towards an ideal. Information that is useable and cost effective to collect have been categorized into six phases of a groundwater development project or programme (Robins *et al.*, 2002): (1) base line surveys to assess demand and likely occurrence of groundwater – reliant on census of user groups and inspection of any existing geological and hydrogeological data and regional summaries; (2) surveys to locate drilling sites – includes remote sensing, geophysics, local knowledge; (3) borehole drilling and construction – technical choice, borehole design and optimum depth; (4) borehole test pumping and water quality assessment – physical and chemical assay of the source; (5) choice of pump – the most effective method of getting water to the people; and (6) long term monitoring – to ensure the water point remains adequate for the community.

Initiating a national network is fundamental to the attainment of a functional groundwater monitoring programme. Many questions may arise from this kind of arrangements: (1) Can all countries in SSA have national water policies that reflect sufficiently on groundwater monitoring and data management? (2) Can we have bilateral, trilateral or multilateral arrangements to monitor groundwater or organize regional groundwater databanks through the African Ground Water Commission or SADC, ECOWAS? and (3) Can there be an inter-African national organization or institutional body specifically designated to monitor groundwater data across the continent? The answers to these questions should reflect the need to evaluate the resource potential in addition to the source or water point potential. Such an effort should draw from the experiences of the World Meteorological Organisation on measures used to gather and monitor climatic data across the globe. The country assessment evaluation carried out for the Southern African Development Community (SADC) reported six of the 14 member states (Lesotho, Mauritius, Namibia, South

Africa, Swaziland and Zimbabwe) have fully fledged national monitoring networks involving water level and some type of water quality measurements (SADC, 2002). In the majority of the remaining countries, some monitoring is going on but it is generally carried out in an *ad hoc* fashion (both frequency and number of monitoring points) or is only carried out locally, usually for wellfields or areas of heavy groundwater use. These can be re-structured to functional and continual monitoring programmes.

For regional monitoring in West Africa (ECOWAS) and Southern Africa (SADC), the Nubian Aquifer Regional Information System (NARIS) is an example. The NARIS, though a transboundary aquifer monitoring unit, contains data on groundwater levels, water quality, groundwater extraction, stratigraphic and hydraulic parameters (Alker, 2008). This information is particularly relevant in regions where groundwater is an important source of community water supply. National governmental inputs and supports are essential. In most countries re-implementation of a programme of data gathering and collation requires institutional building and re-enforcement. Interestingly, modern technology (e.g. computers and database software) will allow data collation to proceed far more easily than it was historically, 20–30 years ago; and there is a hope that the optimal tool for database and GIS-based recording, management, use and publication of information will help Sub-Saharan African nations to manage the data collected.

## CONCLUSIONS

Groundwater management is one of the more important and highly complex of the natural resource challenges facing Africa. Its effectiveness and sustainability is anchored in a more regular and consistent mode of data gathering, which until now has received little attention. Recent calls and recommendations have been on groundwater management in Africa through international groundwater governance and transboundary cooperation. While groundwater management often proceeds at local level, the approach to groundwater monitoring requires a centrally-coordinated body/database for effective data storage and usage. This paper highlights past shortfalls in the construction and maintenance of groundwater databases and offers a practical example from South Africa. Moreover, in order to complement aquifer management on the regional level, national groundwater monitoring at the country level must be strengthened, integrated into water policies and implemented in relevant policy areas. There are a number of centres of excellence for groundwater in Africa and the work of many international organizations and donors provides examples of best practice. These should be harnessed into a structure that will set the pace for a groundwater monitoring network across Africa.

## REFERENCES

Adelana, S. M. A. & MacDonald, A. M. (2008) Groundwater research issues in Africa. In: *Applied Groundwater Studies in Africa. IAH Selected Papers on Hydrogeology,* volume 13 (ed. by S. M. A. Adelana & A. M. MacDonald). CRC Press/Balkema, Leiden, The Netherlands.

Adelana, S. M. A., Tamiru, A., Nkhuwa, D. C. W., Tindimugaya, C. & Oga, M. S. (2008) Urban groundwater in sub-Saharan Africa. In: *Applied Groundwater Studies in Africa. IAH Selected Papers on Hydrogeology,* volume 13 (ed. by S. M. A. Adelana & A. M. MacDonald). CRC Press/Balkema, Leiden, The Netherlands.

Alker, M. (2008) The Nubian Sandstone Aquifer System. In: *Conceptualizing Cooperation on Africa's Transboundary Groundwater Resources* (ed. by E. Scheumann & E. Herrfahrdt-Paehle). German Development Institute (DIE), Bonn, Germany.

Bartram, J. & Balance, R. (1996) *Water Quality Monitoring*. Chapman & Hall, London, UK.

Calow, R. C., MacDonald, A. M., Nicol, A., Robins, N. S. & Kebede, S. (2002) The struggle for water, drought, water security and rural livelihoods. Technical Report British Geological Survey, for UK Department for International Development, British Geological Survey, Nottingham, UK.

Carter, R. C. & Bevan, J. E. (2008) Groundwater development for poverty alleviation in sub-Saharan Africa. In: *Applied Groundwater Studies in Africa. IAH Selected Papers on Hydrogeology,* volume 13 (ed. by S. M. A. Adelana & A. M. MacDonald). CRC Press/Balkema, Leiden, The Netherlands.

Davies, J. (2005) Scoping Study to Assess Hydrogeological Support to WaterAid Tanzania. British Geological Survey. Technical Report CR/05/174C, British Geological Survey, Keyworth, UK.

Davies, J. & Cobbing, J. E. (2002) An assessment of the hydro-geology of the Afram Plains, Eastern Region, Ghana. Brit-ish Geological Survey. Technical Report CR/02/137N. British Geological Survey, Keyworth, UK.

Farr, J. L. Gumiremhete, R. Davies, J. & Robins, N. S. (2005) Groundwater dependence and drought within the Southern African Development Community, Vol. 1. In: *Biennial Ground Water Conference* (Pretoria, March 2005), 97–105.

Foster, S. S. D. (1984) African groundwater development: the challenges for hydrologic science. In: *Challenges in African Hydrology and Water Resources* (ed by D. E. Walling, S. S. D. Foster & P. Wurzel), 3–12. IAHS Publ. 144. IAHS Press, Wallingford, UK.

Foster, S. Tuinhof, A. & Garduño, H. (2008) Groundwater in Sub-Saharan Africa – A strategic overview of developmental issues. *Applied Groundwater Studies in Africa. IAH Selected Papers on Hydrogeology,* volume 13 (ed. by S. M. A. Adelana & A. M. MacDonald). CRC Press/Balkema, Leiden, The Netherlands.

Foster, S. S. D., Chilton, P. J., Moench, M., Cardy, W. F. & Schiffler, M. (2000) Groundwater in rural development: Facing the challenges of supply and resource sustainability. WB Technical Paper no. 463, Washington DC, USA.

JICA (2002) A study of Japan's ODI to Africa, towards sustainable and self reliant poverty reduction in Africa. Report, Institute for International Cooperation/Japan International Cooperation Agency, Tokyo, Japan.

Jones, M. J. (1985) The weathered zone aquifers of the basement complex areas of Africa. *Q. J. Eng. Geol.* **18**, 35–46.

Kouame, K. J. Jourda, J. P. Leblanc, Y. & Biemi, J. (2008) Hydrogeologic modelling and implications for groundwater protection: Case study of the Abidjan aquifer, Cote D'Ivoire. *Applied Groundwater Studies in Africa. IAH Selected Papers on Hydrogeology,* volume 13 (ed. by S. M. A. Adelana & A. M. MacDonald). CRC Press/Balkema, Leiden, The Netherlands.

MacDonald, A. M. & Davies, J. (2000) A brief review of groundwater for rural water supply in sub-Saharan Africa, British Geological Survey, Technical Report WC/00/33, Overseas Geology Series, BGS, Nottingham, UK.

MacDonald, A. Davies, J. Calow, R. & Chilton, J. (2005) *Developing Groundwater*. ITDG Publ., Warwickshire, UK.

MacDonald, A. Davies, J. & Calow, R. (2008) African hydrogeology and rural water supply. *Applied Groundwater Studies in Africa. IAH Selected Papers on Hydrogeology,* volume 13 (ed. by S. M. A. Adelana & A. M. MacDonald). CRC Press/Balkema, Leiden, The Netherlands.

Ockelford, J. & Reed, R. (2002) Participatory planning for integrated RWS and sanitation programmes. Guidelines for planning and designing rural water supply and sanitation programmes. WEDC, Loughborough, UK. (http://wedc.lboro.ac.uk/).

Parsons, R. & Tredoux, G. (1995) Monitoring groundwater quality in South Africa: Development of a national strategy. *J. Appl. Hydrogeol.* **3**(1), 50–56.

Robins, N. S., Davies, J. Farr, J. L. & Calow, R. C. (2006) The changing role of hydrogeology in semi-arid southern and eastern Africa. *Hydrogeol. J.* **14**(8), 1483–1492.

Robins, N., Davies, J., Hankin, P. & Sauer, D. (2002) People and data – the African experience. In: *Groundwater and Human Development* (ed. by E. Bocanegra, D. Martínez & H. Massone), 101–106. ALSUD, Argentina.

Robins, N. S., Davies, J., Hankin, P. & Sauer, D. (2003) Ground-water and data: an African experience. *Waterlines* **21**(4), 19–21.

SADC (2002) Compilation of the hydrogeological atlas for the SADC region. Draft Final Version. Groundwater Consultants Bee Pee (Pty) Ltd and SRK Consulting (Pty) Ltd for SADC Water Sector Coordination Unit, Lesotho, Nigeria.

South African Department of Water Affairs and Forestry, DWAF (2000) *Quality of Domestic Water Supplies*, volume 2: *Sampling Guide*. DWAF, Water Research Commission, Department of Health, Pretoria, South Africa.

South African Department of Water Affairs and Forestry, DWAF (2004) A framework for groundwater management of community water supply. Toolkit for water services: Number 1.1, Department of Water Affairs and Forestry, Pretoria, South Africa.

South African National Water Act (1998) National Water Act. no. 36 of 1998.

UN/ECE Task Force on Monitoring & Assessment (2000) Guidelines on monitoring and assessment of transboundary groundwaters. Institute for Inland Water Management and Waste Water Treatment, Lelystad, The Netherlands.

Vermeulen, A. (2002) Institutional framework for water services provision in rural areas. Department of Water Affairs and Forestry, Pretoria, South Africa.

World Bank (2005) African Water Development Report, Interim Version. World Bank, Washington, DC, USA. (http://www.uneca.org/awich/African_Water_Regional_Report/water_dvpt_report.htm).

WHYMAP (2007) Groundwater resources of the world 1:50 000 000. www.whymap.org.

Wright, E. P. (1992) The hydrogeology of crystalline basement aquifers in Africa. In: *Hydrogeology of Crystalline Basement Aquifers in Africa* (ed. by E. P. Wright & W. G. Burgess). Geol. Soc. London Spec. Publ. 66, 1–27.

Wright, E. P. & Burgess, W. (1992) *The Hydrology of Crystalline Basement Aquifers in Africa*. Geol. Soc. London Spec. Publ. 66, London, UK.

Zektser, I. S. & Everett, L. G. (2004) *Groundwater Resources of the World and their Use.* IHP-VI, Series on Groundwater no. 6. UNESCO, Paris, France.