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Protection of Borehole Water Quality in Sub-Saharan Africa using Minimum Safe Distances and Zonal Protection

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Abstract In Africa, groundwater plays an increasingly important role as a source of potable water, more so in rural communities where the cost implication of routing surface water supplies may far exceed the budgets of local water service authorities. Protection of groundwater resources requires good planning and a concerted effort from the legislative level right down to the enforcement and implementation level. The latter is essential in site-specific management and circumventing potential health threats that may result from the consumption or contact with contaminated groundwater. The reality in sub-Saharan Africa unfortunately is that these institutional structures do not exist and where they do exist implementation is problematic. This paper advocates that whilst zonal protection of groundwater resources is theoretically a good management option for protection of groundwater resource quality, practically its successful implementation can only be carried out once many of the sub-Saharan countries have their legal, institutional and socioeconomic frameworks in place. However, whilst working towards achieving those objectives even protection at a basic level like the implementing of minimum setback distances around groundwater resources and paying close attention to borehole development standards will offer sufficient basic protection to these vital resources.

Keywords Sub-Saharan Africa · Groundwater · Borehole water supply · Contamination · Protection zoning · Microbiological transport · Fractured rock aquifers

1 Introduction

Groundwater in Africa offers precious opportunities for alleviating the misery of the poor and improving living conditions of many; however the complexity of its unseen environment poses a daunting challenge in its management and protection.

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Within sub-Saharan Africa the impingement of potable groundwater quality poses one the greatest threats to the sustained use of our aquifers. Bigger African cities have a complex mix of first world and third world conditions, subjecting the environment to a diverse range of both natural and anthropogenic activities that influence the quality of our groundwater. Coupled with technological developments, population expansion in urban areas resulting from the migration of rural inhabitants to urban centres has resulted in not only an increased demand on water resources but also an increase in contaminant loads. Water resource managers are hence faced with the difficult task of having to protect groundwater resources two fold; both in quality and quantity aspects. Although groundwater resource management encompasses both these aspects, the focus of this paper lies in the quality aspects, particularly microbiological, of water derived from all subterranean sources.

In many parts of sub-Saharan Africa, viral outbreaks, resulting from microbiologically unsafe drinking water and inadequate sanitation, is a daily occurrence. The rate of infectious diseases in developing countries is high and it is mostly the economically disadvantaged who are the most vulnerable (Okeke et al. 2007).The World Health Organisation in 2000 estimated that approximately 4 billion cases of diarrhoea associated with a lack of access to clean water occurs annually in developing countries. Mortality figures from water related diseases are high, with figures in excess of 2.2 million deaths per year (Gleick 2002). Gleick also projects that as many as 135 million people may die from water related diseases by 2020. Even if the Millennium Development Goals are reached, Gleick projects a possible 76 million water related deaths by 2020. The estimates are rather alarming and it is for the wellbeing of our communities that a more proactive approach in groundwater management and protection should be urgently adopted.

Whilst the ultimate and comprehensive protection groundwater resources in sub-Saharan Africa is not a realistic goal, the concept of differentiated aquifer protection seems to indicate a more feasible option in achieving adequate protection qualitatively around different aquifer systems based on their classifications. This concept works on the premise that different aquifers due to their unique socio, economic and environmental importance require different levels of protection (Parsons and Conrad 1998). This protection may range from a simple generic setback distance (often referred to a minimum safe distance) around a water resource to a more complex mechanism of zoning.

Source protection zoning seeks primarily to control land use activities, thus preventing or controlling pollution of groundwater resources. The method takes into account the concept of travel times and minimum safe distances to water supply boreholes and ensures that the time taken for the horizontal travel of the contaminant is sufficient to allow physical and biochemical degradation/dilution of the contaminant (DWAF 2008). The attenuation or elimination capacity of the sub-surface may in some cases reduce or completely eliminate the concentration of these contaminants via natural physical, chemical or biological processes. However delineation of protective zones should also be combined with proper siting and construction of boreholes as well as correct installation of pumps to ensure good water quality.

Though protection zoning around a well or borehole is widely practised in some developed countries, it has proved difficult in their adoption locally in southern Africa, especially in other regional economic communities. Taking into account the developing nature of socio-economic infrastructures in Africa, this paper maintains that a simple minimum distance (or safe distance) is still a good first defence measure against well/borehole contamination for Africa (Xu and Braune 1995; Lawrence et al. 2001) but the concept of protection zoning should be implemented wherever feasible.

2 Concept of Differentiated Aquifer Protection

2.1 Basic Protection Mechanisms

The concept of travel times and minimum safe distances is more apt to biodegradable contaminants than non-biodegradable. A minimum safe distance is that horizontal distance which safely separates a water resource and a potential contaminant source. This distance ensures that the time taken for the horizontal travel of the contaminant is sufficient to allow physical and biochemical degradation of the contaminant. For bacteria and viruses a travel time of 30 days and a minimum distance ranging between 15 and 50 m (depending on aquifer conditions) has been proposed for South African conditions. Distances are calculated using a modification of *Darcy's Law* (Xu and Braune 1995).

2.2 Planning Towards Higher Level Protection

a) Risk Assessment Framework

   The risk of groundwater pollution is determined by the vulnerability of the aquifer to pollution and the loading of waste materials to which it is subjected. The contaminant load is what protection zoning aims to mitigate against. In general the load may also be associated with the extent of development ranging from rural, urban and peri-urban environments to an industrial one including mining activities. The aquifer pollution vulnerability is intended to represent the sensitivity of an aquifer to being adversely affected by an imposed contaminant load (Forster 1987; Forster et al. 2002). The vulnerability depends partly on the extent to which pollutants are attenuated between the location of the waste disposal site and the water table, and partly on the rate with which water and its accompanying pollutants travel through the aquifer including the unsaturated and saturated zones. The nature of aquifer media is of great importance in assessing vulnerability. Based on the above two factors, the types of the risk can be assessed through a framework as shown in Fig. 1.

b) Aquifer classification

   The greater part of sub-Saharan Africa's aquifers are secondary in nature. In adopting a differentiated approach to aquifer protection, where various levels of protection are to given to different aquifers, a more in-depth classification system of aquifers is required. Research in South Africa by Jolly and Reynders 1993, put forth a possible classification system. The three primary criteria offered to assess and establish the importance of the aquifers were: groundwater quality, yield and aquifer use. These factors were used to assess both present and potential future aquifer use. The groundwater quality and yield were seen as the main contributing factors in the assessment with the current or future potential use used to upgrade or downgrade aquifer importance (Jolly and Reynders 1993).

   This methodology was later modified by Parsons and Conrad 1998 who came up with the following classification system for South Africa as depicted in Table 1.

   Using these aquifer classifications and vulnerability classes, Parsons and Conrad (1998) were also able to assign aquifer contamination susceptibility classes for the different aquifer types.

c) Legislative framework

   The legislative framework under which the protection of groundwater can be effected ranges from the formal promulgation of environmental legislation at national government level to policy formulation, public participation, land use planning and

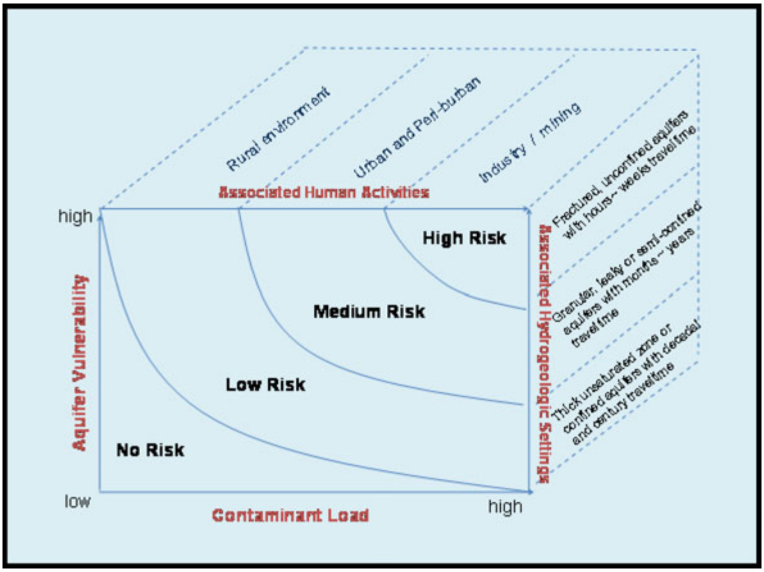

Fig. 1 Groundwater risk assessment framework

management, formulating tools for pollution control and finally at the local level enforcement (WHO 2006).

South Africa is probably one of the most proactive sub-Saharan African countries in this aspect. The legislative framework in South Africa stems from the Constitution (Act No. 108 of 1996) which outlines in Section 24, that any development and use of our natural resources must be environmentally sustainable. The protection and sustainable development of the nation's water resources are further governed by the National Water Act (Act 36 of 1998). Before any licensing is granted, initial consideration will be given to the Reserve (both human and ecological), international obligations, future requirements and existing users. One of the tools developed in accordance with chapter 3 of the NWA, is the resource directed measures process (RDM), the groundwater resource directed measures (GRDM) in context of groundwater. The GRDM includes the classification of water resources, the setting of the reserve and the setting of resource quality objectives (NWA 1998). The proposed protection measures of minimum safe distances and zonal protection can ideally be slotted within this

Table 1 Modified aquifer classification (Parsons and Conrad 1998)

Aquifer type	Description
Sole source aquifer	Aquifer supplying more than 50% of urban domestic water where there is no alternative source of water
Major aquifer	High yielding aquifer system of good quality
Minor aquifer	Moderately yielding aquifer system of moderate quality
Poor groundwater region	Low to negligible yielding aquifer system of moderate to poor quality
Special aquifer region	Aquifer system designated as such by the Minister of Water Affairs and Forestry, after due process

framework allowing for the safeguarding of the quality aspects of the resource objectives under the overall umbrella of the GRDM.

Whilst the GRDM process works mainly at managing water use at catchment level, the national water resource strategy (NWRS) strategically directs the management of water from a national perspective, offering long term planning to meet the challenges of South Africa's aridity and limited water supply (DWAF 2004). The NWRS also encompasses the ideals of the policy and strategy for groundwater quality management in South Africa (DWAF 2000), which describes the means and measures available to achieve groundwater quality management. This aspect has been further elaborated on in the National Groundwater Strategy (2008) which specifically mentions zonal protection as an option for groundwater protection.

Even if all the environmental legislation and policies were in place there are still specific challenges related to authorisation, protection and management of groundwater resource use. The "hidden" nature of groundwater makes it difficult to detect when a person is using or impacting on quality of the water without the necessary authorisations. Groundwater monitoring is also not always effective in determining levels of protection and sustainable utilisation of aquifers, notably when all users are not registered and/or complying with their licence conditions. Enforcement of these laws and policies is thus one of the many obstacles sub-Saharan African countries have to deal with.

2.3 Protection Zoning

This strategy involves the delineation of zones around a water resource for differentiated levels of protection (See Fig. 2 below). Each zone offers increasing strictness in land use constraints moving in from the outer protection zone to the wellhead operational zone. By forming protective zones around important water sources, land uses that may have detrimental effects on groundwater can be controlled. Certain uses can be allowed under predetermined conditions, the intensity of development limited, and the locations where certain land uses are to be carried out, specified.

The wellhead operational zone is the primary protection zone, which allows for protection of the immediate area around a borehole. The distance can be determined according to the safe minimum distance concept (Xu and Braune 1995). The hydraulic

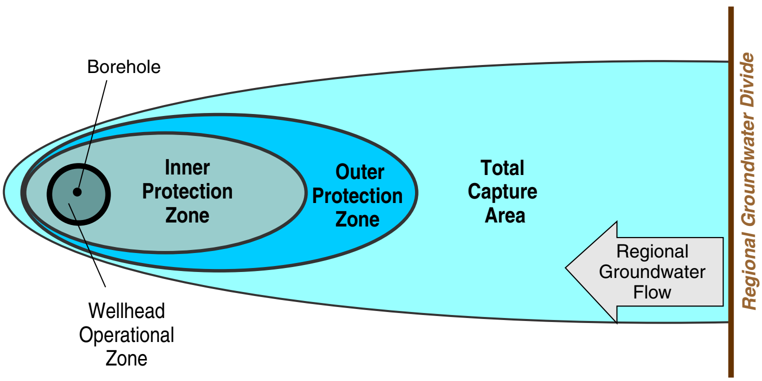

Fig. 2 Schematic representation of protection zones around a water source (Nel et al. 2009)

gradient and flow direction will determine shape and size of the zone. In South Africa this minimum distance ranges between 15 and 50 m depending on the geological nature of the aquifer. Ideally, in this zone no other activity except abstraction should be permitted. Careful control should be exercised to prevent pollutants reaching the source (Forster et al. 2002; Xu and Braune 1995). The inner protection zone is based on travel times required for the horizontal movement of microbiological contaminants in the subsurface environment. The natural attenuation processes of the unsaturated zone will filter out microbiological pathogens deposited in the subsurface environment. Flow times can vary between 10 and 400 days depending on the life span of the contaminant. However a 50 day travel time is considered reasonable to define this zone in terms of both economical and safety reasons (Jolly and Reynders 1993; Forster et al. 2002). The outer protection zone works on protection of the resource on an aquifer level. The recharge area of the aquifer is protected from pollutants that can affect water quality on a long-term basis. These are pollutants that are not easily decomposed and are persistent in the subsurface environment. A 500 day travel time has been cited by Jolly and Reynders 1993 for South African conditions. This travel time however, can be increased or decreased according to the protection needs of the aquifer as well as the vulnerability of the aquifer.

3 Developed Vs Developing

Traditionally in sub-Saharan Africa, not much emphasis has been placed on aquifer protection against pollution. Focus has mainly been on service provision rather than resource protection and management. Water resource managers now realise that there is an increasing need to assess their aquifers and put in mitigation measures such that it ensures sustainability of their resource.

From a UNEP-UNESCO led project (Xu and Usher 2006), involving 11 African countries assessing their major supply aquifers for pollution vulnerability, several factors have been identified as potential reasons as to why African aquifers are under increasing stress. These factors are repeatedly echoed with all 11 participants and include:

1. The migration of rural communities to urban areas in search of better lifestyles has seen rapid population growths within urban areas, which are not designed in terms of service infrastructure to cater for these large numbers.
2. Indiscriminate siting of waste disposal facilities and on site sanitation poses as some of the primary microbiological threats to water resources.
3. Also contributing to aquifer pollution is improper construction of boreholes and wells, in many cases with no protective measures to prevent ingress of contaminated surface water directly into the wells.
4. Population density and socio-economic setting were also seen as contributing factors to pollution. Higher coliform counts were encountered in settlements within the lower income brackets.
5. The greatest threat however, is the lack of management and lack of protection strategies/frameworks to minimize and prevent future contamination.

Recently there has been a movement towards a blanket adopting of protective management measures from economically more developed countries by the developing counterparts. Whilst the ideology behind this proactive response is encouraging, several authors warn against a direct translation and implementation of those measures used in economically developed countries to developing countries (Robins et al. 2007; Kreamer and Usher 2010). Ideally a degradable contaminant like pathogenic micro-organisms in the fractured rock aquifers should be prevented through appropriate management strategies like the zoning method, but these must be adapted to sub-Saharan Africa's specific needs using the experiences of developed countries, including the failures and successes needs (Kreamer and Usher 2010).

Groundwater protection zoning has been successfully implemented within many areas in the United States of America, according to the guidelines set out by the Environmental Protection Agency (EPA 1987) and within many of the countries of the European Union (Robins et al. 2007). Nations like the USA and UK seem to have succeeded in implementing source protection zones due to having their institutional, legal, technical and socioeconomic frameworks in place (Robins et al. 2007). All these frameworks are not necessarily in place yet in most developing countries. Table 2 shows the extent of groundwater management and protection in Africa in relation to some of the more environmentally active and economically developed countries.

What is important to note from Table 2 is whilst Africa may experience the same type of contaminants which threaten groundwater quality as many developed countries, the difference lies in the lack of a definitive legislative and institutional framework. It is also evident that most African countries do not have dedicated monitoring networks whose data can be used to quantify the extent of the impacts of groundwater. Those that do have dedicated monitoring networks rarely include microbiological contaminants as a standard constituent to be analysed regularly. Also where the networks do exist, they are subjected to neglect, under funding and lack of focus.

Data collection and management is vital and forms the foundation of higher level protection and management of any resource. The lack of significant data in many sub-Saharan countries translates to very few of these countries developing their own set of water quality guidelines specific to their unique set of conditions, as well as very little being done in terms of further protection measures being implemented. In these developing countries, focus is preferentially placed on provision of services rather than monitoring programs or enforcement of water quality standards. This results in a lack of continuous and reliable data to quantify the extent of microbiological pollution of the groundwater resource and thus hinders the effective management of these resources.

The high incidences of water related diseases in developing countries are a clear indication that of the groundwater resources are to some extent microbiologically impacted on. The Human Development Report (UNDP 2006) reports that 5 billion cases of diarrhea in children are reported per annum in developing countries. It is also approximated that 1.8 million children die per annum due to illnesses related to unclean water supplies. In a study regarding fatality rates resulting from an outbreak of cholera in several southern African countries in 2001, Malawi, Zimbabwe, Swaziland, Zambia and Mozambique reported fatality rates greater than 20–50% (Chabalala and Mamoo 2001). These staggering figures clearly indicate that many African countries need to urgently work towards some level of protection even if it is just basic measures like minimum safe distances and paying attention to borehole construction methods which will render some level of immediate protection to the resource. This is despite not having many of the frameworks in place. Even a simplistic level of protection is better than it being completely absent.

There is a definite need for protection strategies which may include land use restrictions to activities that will impact on the resource in a detrimental manner. But in order to assess which resource needs to be protected and to what extent protection is required many sub-Saharan countries will need to address the gaps as outlined above.

Table 2 Groundwater management and protection frameworks: developing vs developed

Area	Legislative framework	Monitoring networks	Water quality guidelines	Protection zoning	Vulnerability mapping
Sub Saharan Africa	Not available for many sub-Saharan countries	No. Adhoc monitoring for chemical and microbiological	WHO guidelines widely used, Botswana Bureau of standards 32, Ghanian water quality standards, Nigerian Federal Environmental Protection Agency standards, Kenyan Bureau of standards	No.	DRASTIC maps done on a regional basis for several African countries
South Africa	National Water Act	National and regional chemical monitoring networks. Adhoc microbiological monitoring	South African water quality guidelines developed	Policy feasibility stage	DRASTIC maps done on national scale
USA	Clean Water Act	Yes	Environmental protection agency ground water rule	Wellhead protection zones implemented	Yes
Canada	Canada Water Act	Yes	Canadian drinking water quality guidelines	Yes	Yes
England	Water Act 2003	Yes	Yes	Protection zones delineated countrywide	Yes
Germany	German Federal Water Act	Yes	German drinking water regulations	Yes—Mainly agricultural settings	Yes

4 Steps Towards Implementation of Protection Zoning? The South African Story

4.1 Situational Assessment

The differentiated approach adopted by South Africa for groundwater consists of three tiers (Xu and Reyders 1995). The first tier addresses basic protection standards, guidelines such as safe location of latrines, etc. to minimize impact of point sources in all aquifers country-wide. The second tier is the approach of planned protection of resources through classification, mapping and education to regulate point and diffuse sources at regional scale. The third and final tier is source protection zoning. This third tier forms an advanced stage of groundwater protection and is seen as a long-term objective. In order to implement zoning, detailed information regarding current land use, geohydrological characteristics and groundwater sources is required (Xu and Braune 1995).

Currently South Africa is leading in sub-Saharan Africa in formulating and adopting policies in groundwater resource protection and particularly on protection zoning. The South African government recognizes that securing sustainable groundwater resources lies in the effective management of the resource on a local, regional and national scale. In the development of the Department of Water Affairs National Groundwater Strategy, 2010; it lists a protection zoning policy as one of the options that can be adopted in its plan for sustainable groundwater management. This document also points out that the protection zoning strategy is not widely practiced in South Africa but emphasizes that such a policy is economically and environmentally important (DWA 2010).

In 2005 a research project was initiated by the national Department of Water Affairs to address the feasibility of introducing such a policy (DWAF 2008). Having completed the groundwork in protective legislation and classification of the country's aquifers, South Africa is now in a position to move into the differentiated protection strategy of zoning. The project is currently in the feasibility stage.

The long term benefit of implementing such a project would result in considerable economic savings as was depicted by Nel et al. (2009) on analysis of the Delmas typhoid outbreak. This outbreak received national news coverage when it was discovered that the outbreak was as a result of contamination of groundwater which was consumed by the local community. A combination of the bucket sanitation system, standpipes and dolomitic aquifers proved to be fatal for five people (Pienaar and Xu 2007). This scenario permitted rapid movement of microbes to the groundwater via fractures and solute channels, especially in the non-serviced informal areas (Le Roux and du Preez 2008). Nel et al. (2009) were able to show that the costs associated with implementing and managing a zoning strategy over a 10 year period for that particular aquifer system was superseded by the costs associated with the reactive management post the infectious incident. This indeed proves that proactive management and protection of groundwater resources are less costly over a longer period than dealing with problems once they crop up (Nel et al. 2009)

4.2 Implementation

The feasibility document on protection zoning (DWAF 2008) identifies various implementation steps for zoning. These range from highly technical steps to addressing social issues and post zone delineation monitoring and evaluation. These steps are:

- Stakeholder involvement and public awareness
- Aquifer characterization
- Risk Assessment and identification
- Zonal delineation
- Data management
- Post delineation monitoring and assessment

Despite the South African government having recognized the importance of such a policy this project still remains at the feasibility stage to date.

4.3 Hindering Factors

Even though South Africa has been exploring the option of implementing a zoning policy it is very likely that there are several factors that might hinder the successful implementation of such a policy and the end result will be a phased implementation of the policy based on how well the issues affecting the implementation factors mentioned in section 4.2 are addressed. Some of the issues are addressed below.

Socio-Economic Impact One also needs to assess the socio-economic impact of restricting activities around water resources. It is often the case that many of the very activities that sustain rural and poorer communities occur on land within the protection zone. In delineating the zones a balance needs to be maintained between resource protection and socio-economic development. Placing large portions of land under land constraints might lead to resistance from communities as the perceived loss of income generated from the land will supersede the importance of a safer water source. This resistance due to perceived loss of income could possibly be eliminated by monetary compensation for the loss of agricultural production from the zoned land.

Stakeholder Collaboration It is important that an extensive public participation and education proramme be held before implementing such a policy. Stakeholder support is vital to a zoning policy being successful as zoning actually restricts future land uses and may impose onerous obligations on the current land users/owners.

Lack of Technical Capacity The lack of sufficient local and technical knowledge and capacity in contaminant travel characteristics within the specific fractured rock aquifers present on the African continent are also factors in hindering implementation of groundwater protection zones. Capacity building in sub-Saharan Africa in regards to technically skilled groundwater professionals is urgently required (Kreamer and Usher 2010; Robins et al. 2007)

Lack of Sufficient Data Zoning as described in Nel et al. (2009) seems to be quite a data intensive activity. Currently there appears to be a huge gap in data across the sub-Saharan continent in regards to groundwater (Kreamer and Usher 2010). This data is pertinent for one to conduct risk assessments, vulnerability mapping and delineation of the zones. It is likely that in South Africa, sufficient data may exist for such assessments, however much of the data has not been captured electronically on the proper databases (Kreamer and Usher 2010).

Scale of Groundwater Development Many socially important aquifers are often lower yielding single boreholes rather than high yielding wellfields (Robins et al. 2007). It is the rural low yielding yet socially important resources units that require greater levels of protection as it is often the case that water from these resources are consumed without any prior treatment unlike municipal well fields which undergo treatment and purification if required. Also in terms of the high volume of low yielding rural boreholes compared to the smaller number of higher yielding municipal wellfields, delineating zones around the rural boreholes may prove more time consuming and difficult.

Levels of Legal Framework Development Across the sub-Saharan continent there are different levels of legal development. There may be little or no legal instruments for groundwater protection versus there are such instruments but they are toothless and hence cannot be implemented in practice. Generally within most sub-Saharan countries very little legal instruments exists to enforce such a strategy. However even though South Africa is moving towards policy formulation, they are still struggling on the ground level to enforce these laws. This may be as a consequence of understaffing, lack of appropriate technical skills, lack of institutional structures, lack of appropriate funding. Enforcement may also be difficult since the NWA has been fashioned around legislation from various developed countries but the reality is that conditions in SA are still developing world. It is quite evident in South Africa that whilst the legislation is in place to address protection of groundwater resources, the policies to effect this protection often lags behind the legislative framework.

Lack of Sectoral Integration Another important hindering factor would be the lack of sectoral integration of water resources management, including groundwater, across the

African continent. This is evident even though many great initiatives are on the table, like the river basin organization, lake organization, etc. With the new establishment of AMCOWs Africa Groundwater Commission, the situation would be rectified in the manner that groundwater, as a basic guarantee for water security in vast rural Africa can be realized.

5 Way Forward

Provision of safe drinking water to any community is of utmost importance. In rural Africa, the problems surrounding provision of water for basic human needs are numerous from supply to quality. Groundwater is the most logical choice in most rural areas, though one needs to take into cognisance all the potential problems as highlighted in this paper, especially in terms of microbiological pollution. In order to provide a reliable service of clean safe water, African groundwater practitioners need to address various issues:

First and foremost, groundwater developers should ensure that groundwater resources have the appropriate sanitary seals and wellhead protection mechanisms as well as boreholes are sited hydraulically upgradient of point pollution sources. Deeper aquifers with well constructed boreholes (appropriate casing lengths and sanitary seals) should be investigated. As can be seen from the UNEP-UNESCO led project (Xu and Usher 2006) many of the shallow easily accessible aquifers are already polluted and an alternative needs to be investigated.

Knowledge on the state of groundwater is minimal in most African countries. Complete surveys and hydro-census needs to be conducted to establish baseline technical data on existing infrastructure (groundwater usage, well construction, pollution issues, water resource potential). Once conducted, the data can be utilized to determine aquifer pollution vulnerability and subsurface contaminant loads. Pending these assessments protection measures can be prioritized and initiated.

Many countries need to increase focus on groundwater monitoring programmes for both quantitative and qualitative data, with more specification on microbiological qualitative monitoring to be carried out. This will help paint a clearer picture of the state of resources and help with planning of protection measures. Not enough microbial monitoring data are available allowing, characterization of microbial quality trends.

Leading from this, appropriate management plans specific to socially important and productive wellfields should to be drawn up. A well managed and routine system helps in identification of problems before they become detrimental.

The current geo-technical skills shortage within the African continent is another factor that needs to be urgently addressed. Africa’s hard rock aquifers are complex in terms of understanding contaminant transport. In order to fully understand groundwater and contaminant movement in a dual porosity system one requires sophisticated and well planned experiments which are usually expensive to conduct and require highly technical skilled people.

Also changing and improving of on-site sanitation technologies would greatly assist in minimizing risk to pollution of groundwater resources. Whilst the urine diversion system is the more expensive option as compared to pit latrines and VIP systems, it can be seen that in the longer term the environmental and health benefits far outweigh the initial higher cost implication (Von Munch and Mayumbelo 2007).

The results from the UNEP-UNESCO led project (Xu and Usher 2006), suggest that land use constraints as required in zoning can be technically justified, but will require refinement of exact delineation areas for high loading microbiological contaminant sources. The study also highlights the need for integrated land-use planning and geotechnical mapping in order to minimize contamination and better protect groundwater resources as expansion of the metropolitan area occurs.

At a final and most advanced level, the application of land use constraints around water resources must occur in conjunction with a public participation program which creates awareness around water quality issues with local communities. This should take into account socio-economic impacts on communities, environmental, health and service delivery issues as well.

6 Conclusion

It is evident that our shallow groundwater resources are at risk of pollution due to rapidly growing populations, increases in intensive agriculture and change in land use activities.

Although zoning offers protection on a technically more accurate basis with higher confidence levels against a wider range of contaminants, based on the current social, economic and institutional capacities in sub-Saharan Africa this may not presently be the most feasible option to exclusively pursue and implement for groundwater protection. The idea of minimum safe distances remains the best current option to institute the first line of defense in protecting the immediate area around a groundwater source. However the implementation of this measure should not halt the development of a more advanced protection strategy such as zoning for long term implementation and benefits.

Whilst studies like that of the UN agencies and other institutes assist in giving much required indication of the state of African groundwater resources and will help in defining aquifer differentiated protection strategies including the zoning approach, it is imperative that the gaps identified within the groundwater management sector within sub-Saharan Africa, be focused on and addressed in the near future. It is only once the foundation is firmly laid by addressing these issues can the management of groundwater resources be effected successfully, including the successful implementation of differentiated zones.

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