Feasibility of Zoning for Groundwater Protection in Africa.

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ABSTRACT

Groundwater studies in many African countries have showed that groundwater contamination is seriously threatening the use of the existing water supplies. This contamination of water supply aquifers in Africa is due to the improper placement of land based activities like agriculture, industries, waste disposal and excreta disposal. Abstraction related contamination is also occurring due to the capturing of contaminated surface water and sea water encroachment.

Sporadic outbreaks of water borne diseases such as cholera and dysentery have been recorded. Communities with limited water cannot consider resource protection until their supply is sufficient and therefore often have no option than using the available contaminated water.

Groundwater protection zoning is a possible supplemental methodology for groundwater protection that includes land use planning in groundwater management. Long-term protection through the use of protection zones will be balanced by the need for economic and social development by allowing more activities outside the protection zones. Stakeholder involvement is very important in this management process where protection will be implemented to benefit their socio-economic needs.

The delineation of a protection zone is the process of determining what geographic area should be included in a protection zone program. This area of land is then managed to minimize the potential of groundwater contamination by human activities that occur on the land surface or in the subsurface.

Groundwater protection zoning can prevent the contamination of drinking water in an integrated way and can be applied in many instances. An effective legal and institutional framework will benefit the implementation of protection zoning for sustainable development and management of the water resources. Stakeholder participation will however be the driving force to enable the prevention and control of water pollution for the benefit of the community.

1INTRODUCTION

Groundwater studies in many African countries have showed that groundwater contamination is seriously threatening the use of the existing water supplies. This contamination of groundwater is associated with various types of human activity while the need for additional development often creates more potential sources of contamination to groundwater. Contamination of groundwater resources affects the users and ecosystems through negative health effects and economic cost of sickness and deaths of humans and animals.

The objective of this paper is to highlight the role of groundwater protection zoning in Africa as a management option to ensure sustainable safe drinking water. Delineation of groundwater protection zones aims to reduce the effect from contamination, based on the fact that all contaminants do not pose the same risk to the groundwater users, and that the contamination flow path in the aquifer might not affect users far away or in another part of the aquifer.

A differentiated approach that can allow protection of drinking water while allowing development is therefore promoted. Groundwater protection zoning is a protection method that can selectively protect water-supply areas from contaminants while allowing development in areas outside the protection zones. Groundwater protection zoning is a pro-active protection approach practiced for drinking water supplies in most developed countries.

The structure of this paper is as follows: First the value of groundwater in Africa is placed in perspective. Secondly a description of the groundwater contamination problems experienced in Africa is made. From this basis we then consider groundwater protection zoning as a possible solution. Finally some challenges and recommendations are made towards the implementation of groundwater protection zoning as a supplemental protection method in Africa.

2VALUE OF GROUNDWATER IN AFRICA

Groundwater resources from drilled boreholes, dug wells and springs represent a significant portion of the current water utilization in both the urban and rural parts of Africa. In urban centers, groundwater supplies are important as a source of relatively low cost and generally high quality municipal and private domestic water supplies. In a rural context, groundwater is the main source for agricultural irrigation and will be the key to providing additional resources for food security.

Groundwater also plays a significant role in sustaining wetlands and other ecosystems in Africa. Many wetlands have been damaged and even destroyed due to the uncontrolled abstraction of groundwater in their vicinity. Wetlands and their ecosystems supply various goods and services to the people living near them and must be protected for the benefit of the people.

Current groundwater use by African countries represent between 15 and 71 percent of their total use (Table 1). Groundwater use is expected to increase to meet the future water needs for basic water uses and development of industry and agriculture.

Table 2.1 Groundwater use by African countries involved in recent UNEP/UNESCO sponsored projects.

Country	Population (Million)	Ground-water (10^9 m^3)	Ground-water %
Botswana	1.6	1.7	50%
Burkina Faso	12.6	9.5	42%
Cameroon	16.2	57	17%
Cote d'Ivoire	16.8	37.7	33%
Ethiopia	67.7	45	22%
Ghana	20.3	26.3	47%
Kenya	31.2	3	15%
Mali	11.4	20	28%
Niger	10.7	2.5	71%
Nigeria	130.0	87	28%
Senegal	10.6	7.6	24%
South Africa	43.7	4.8	15%
Zimbabwe	11.4	5	27%

3GROUNDWATER CONTAMINATION IN AFRICA

Most African countries have experienced difficulties coping with the expansion of their cities due to urbanization and rapid population growth (Nkhuwa et al., 2005; Banoeng-Yakubo, 2005; Seynabou, 2005; Lupimo, 2005), with most people downgrading to high-density settlements (Nkhuwa et al., 2005). In Zambia and Ethiopia human activities over especially the aquifer recharge areas have contaminated groundwater with serious public health implications and risks for users in the future (Nkhuwa et al., 2006; Ayenew et al., 2005).

Groundwater studies in several African countries show that the contamination of water-supply aquifers is due to the improper placement of land-based activities such as agriculture, industries, waste disposal (Banoeng-Yakubo, 2005; Boukari et al., 2005; Nkhuwa et al., 2005; Seynabou, 2005; Usher et al., 2004) and excreta disposal (Nkhuwa et al., 2005; Seynabou, 2005; Lupimo, 2005; Vogel, 2005; Chilume, 2005). Sporadic outbreaks of water borne diseases such as cholera and dysentery have been recorded (Banoeng-Yakubo, 2005) with polluted groundwater causing an outbreak of gastro-intestinal disease claiming 5 lives in Delmas, South Africa in August 2005 (Aleobua, 2005).

Abstraction related contamination is also occurring due to the capturing of contaminated surface water (Ayenew et al., 2005; Lupimo, 2005) and seawater encroachment (Banoeng_Yakubo, 2005; Seynabou, 2005; Lupimo, 2005).

Communities often have no option than using the available contaminated water. Communities with limited water cannot consider resource protection until their supply is adequate (Usher, 2005). Contaminated water used for domestic purposes can pose potential health risks (Pool, 2005; Tredoux and Colvin, 2005) and even deaths (Tredoux and Colvin, 2005; Aleobua, 2005). The short term solution most commonly recommended to the communities is the use of bottled water (Tredoux and Colvin, 2005). This is often not viable with increasing levels of poverty and unemployment (Massone and Sagua, 2005). Livestock are also affected by contaminated water supplies (Tredoux and Colvin, 2005), causing reduced reproductivety and deaths, resulting in substantial economic implications to both the formal and informal farming communities.

Inadequate legislation often exists to protect against pollution of groundwater (Nkhuwa et al., 2005; Lupimo, 2005). But even in countries with proper legislation the implementation and prioritization of groundwater protection are often not done (Aleobua, 2005; Nel and Bishop, 2006; Mwango and Githae, 2005). Staffing, budget, logistics and suitable expertise are typical limitations of management institutions (Aleobua, 2005; Nel and Bishop, 2006). Funding is probably the biggest challenge to implement groundwater protection strategies for all formal and informal management institutions (Pienaar, 2005; Aleobua, 2005).

4GROUNDWATER PROTECTION ZONING

The delineation of a protection zone is the process of determining what geographic area should be included in a protection zone program. Transport of contaminants towards a well can be along the groundwater flow path as well as from the wellhead itself (Robins and Chilton, 2005; Bradbury, 2005). This area of land is then managed to minimize the potential of groundwater contamination by human activities that occur on the land surface or in the subsurface.

Commonly three to four zones are delineated to achieve different levels of protection (Jolly and Reynders, 1993; Chave et al., 2005), namely:

- A *Wellhead Operational Zone* immediately adjacent to the site of the borehole or wellfield to prevent rapid ingress of contaminants or damage to the borehole (also referred to as the '*Accident Prevention Zone*').

- An *Inner Protection Zone* based on the time expected to be needed for a reduction in pathogen presence to an acceptable level (often referred to as the 'Microbial Protection Area').
- An *Outer Protection Zone* based on the time expected to be needed for dilution and effective attenuation of slowly degrading substances to an acceptable level. A further consideration in the delineation of this zone is sometimes also the time needed to identify and implement remedial intervention for persistent contaminants.
- A further, much larger zone sometimes covers the total catchment area of a particular abstraction where all water will eventually reach the abstraction point, such as at springs. This is designed to avoid long term degradation of quality.

It is important to provide guidance on activities which are either acceptable, unacceptable or need to be controlled in various protection zones. In some countries such lists are very extensive and specific. In others, general guidance is issued. With each protection zone comes land use constraints. These constraints are of increasing strictness moving from the outer protection zone to the wellhead operational zone.

Protection Zone Delineation approaches range from relatively simple methods, based on fixed distances, through more complex methods, based on travel times and aquifer characteristics, to sophisticated modelling approaches using log reduction models and contaminant kinetics. Uncertainty of the underlying assessment of contamination probability is reduced with increasing complexity (Chave et al., 2005).

The choice of delineation method depends upon factors such as aquifer type, the perceived level of threat to the aquifer, the size and vulnerability of the population that may be potentially affected, and the economic resources that a community is willing or able to spend (WDEQ, 2001; Massone, 2005). The accuracy of the resulting map is directly related to the money and time invested.

Fixed radius methods are best used for rule of thumb type protection at the accident prevention zone level, preventing short circuit contamination of the aquifer via the borehole itself. This can be implemented at almost no cost to the water supply authority.

Flow system mapping forms a logical next delineation method that is easy to implement and produces a total catchment area. The flow system mapping method is one of the recommended methods for aquifers showing conduit flow characteristics. The data required for flow system mapping also forms the base line data needed for the more advanced methods. The data needed for this method can be obtained from normal national- and aquifer-level monitoring programmes.

Analytical modelling can be implemented even with limited data available to achieve quite advanced 2-dimensional models. The data availability will directly influence the level of certainty in the results. The software is easy to use and can be implemented and updated by local authorities and Water Users' Associations.

Numerical models can be implemented in complex geological terrain where the importance of the resource can justify the additional cost of data and modelling expertise. The models can only be updated and implemented by experienced modellers.

The most sophisticated approaches to groundwater protection zone definition are based on calculated log-reductions in microbial concentrations or reductions in chemical concentrations that can be achieved through attenuation and dilution as contaminants move through the soil, unsaturated zone and saturated zone. These approaches require much greater knowledge of local conditions and the expected reductions that may be achieved through attenuation. They do, however, provide much more realistic estimates of the land area where control should be exerted on polluting activities, and thus may be components of quantitative risk assessments. These may involve assessment of the hazard arising from a particular activity, examination of the vulnerability of the underground water to pollution, and consideration of the possible consequences which would occur as a result of contamination.

5 BENEFIT OF GROUNDWATER PROTECTION ZONING

5.1 Social- Economical component

Protection zoning focuses on the protection of individual wells or well fields for the direct benefit of the users of the resource. The protection zones provide guidance to the users on activities which are either acceptable, unacceptable or need to be controlled for their own benefit. Zoning initiatives are therefore often supported by local users due to the health benefits as well as local user management of well fields (Bradbury, 2005; Lupimo, 2005).

This benefit to the community can be expressed in economic terms and can be based on a change in welfare due to human and animal health from water use (Mbatha, 2005). Groundwater resources can therefore be protected by economic means (Liu, 2005) with the economic values determining the appropriate level of protection (Mbatha, 2005; Liu, 2005).

The value of water as a social good must, however, not be compared to water as a business creating a situation where water supply companies prioritize company economic benefits over social well-being (Massone and Sagua, 2005).

5.2 Political and Institutional support

High economic valuations can justify extensive policy intervention with health benefits to the users and financial savings to the management institutions. By selectively prioritising and controlling polluting activities around abstraction points, groundwater protection zones can have significant economic benefits to the water-supply as well as management institutions (Chave et al., 2005).

Limiting land-based activities through the use of protection zones will be balanced by the need for economical and social development by allowing more activities outside the protection zones (Pienaar, 2005). Stakeholder involvement is very important in this management process (Lupimo, 2005), where protection will be implemented to benefit their socio-economic needs (Pienaar, 2005).

5.3 Scientific Expertise

Socio-economic needs can already be considered in the scientific assessments. Some scientists include a social component by calculating a social vulnerability index (Massone and Sagua, 2005). Areas with high social vulnerability can be prioritized for groundwater protection by combining the social vulnerability with the scientific data to reach a more realistic assessment. The pathway, role and importance of groundwater in terms of drinking water and ecosystem support can be used to guide managers on protection prioritization.

One of the drawbacks of primary aquifer protection zoning strategies is that contaminants are assumed to be transported at the average linear velocity of groundwater flow (Taylor *et al*., 2004). In the African context this assumption is often incorrect as groundwater flow in fractured rock media is not linear but highly variable due to the variability in hydraulic conductivities and may follow preferential pathways. Recent scientific advances have improved the traditional application of protection zoning methods in primary aquifers to also include fractured rock and karst aquifers (Bradbury, 2005). These include improvements in borehole data collection and analysis methods enabling scientists to collect data applicable to fracture flow conditions (Bradbury, 2005). Improved modeling tools further enable the simulation of advanced stochastic and fracture models (Bradbury, 2005), but also aquifers with limited data (Cobbing, 2005) as often found in Africa. For certain homogeneous geologic conditions, a "rule of thumb" protection zone can be established based on data and experience (Robins and Chilton, 2005; Aleobua, 2005).

Most of the health risk for humans is due to microbiological and nitrate contamination of the water source (Robins and Chilton, 2005). Analysing groundwater flow data together with microbial size, lifespan and pH conditions of soils gives a relatively good indication of the potential distance to be travelled by microbial contaminants, allowing sufficient time for inactivation. This approach would have easily prevented the loss of lives in Delmas, with the gastro-intestinal virus having a lifespan of 7 days outside the host (Pool, Pers Com, 2005).

6CHALLENGES

The goal of a protection zone is to protect public water-supply areas from contaminants which may have adverse effects on human health. Communities need to be knowledgeable about their drinking water resources to avoid the negative economic impacts that groundwater contamination could cause. Verification studies are needed to quantify uncertainties in many of these more complex aquifers, especially fractured aquifers (Bradbury, 2005; Liu, 2005; El Arabi, 2005).

An inventory of land use and potential contamination sources must be done (Ayenew et al., 2005; Boukari et al., 2005), due to the linkage between land uses such as manufacturing industries, horticulture and landfills and groundwater contamination in an area (NWQMS, 1995; Usher et al., 2004). A benefit of controling land use through the application of protection zones is that economic development and resource protection can be balanced in a differentiated approach. But countries, agencies and stakeholders in Africa must work together in a focused way to achieve protection for sustainable development.

The widespread awareness of key stakeholders at all levels about groundwater, its developmental role, its hydrological and ecosystem function, its vulnerability to human impacts and approaches to its sustainable utilization will be needed to achieve sustainable development of this critical resource. The interaction of groundwater with other water sources especially needs to be promoted as an integral part of the national water resource (IWGP-Legal Group, 2005). There is an immense challenge of trying to narrow the interfaces between science and government processes and science and society processes to achieve national and regional development goals.

There is a need for appropriate capacity, including policy and legislation, appropriate institutions and human resources to plan and implement sustainable groundwater utilization at all levels.

7CONCLUSION

Groundwater supplies in many African countries are contaminated due to the improper placement of land-based activities such as agriculture, industries, waste disposal and excreta disposal. Groundwater protection zoning can give guidance on the management of these negative land uses and aims to prevent contamination of land above aquifers contributing to boreholes and springs. Groundwater protection zoning will benefit the users and can be applied in many instances in Africa.

Protection strategies must be scientifically and legally sound and can be implemented in a lasting and strategic prevention plan only by involving the users. Social and natural variables are integrated through protection zoning, as well as the local knowledge of users, to achieve an integrated scientific knowledge base. An effective legal and institutional framework will promote the implementation of protection zoning for sustainable development and management of water resources, but stakeholder participation is the driving force for prevention and control of water pollution.

REFERENCES

Aleobua, B., 2005 *Human Induced Impacts on Groundwater Quality: The Delmas, R.S.A. Case* Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Ayenew T, Alemayehu T, and Legesse D, 2005 *Aquifer Vulnerability Mapping and Water Pollution in the Akaki River Catchment, Central Ethiopia*. Addis Ababa University, Ethiopia. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Banoeng-Yakubo, 2005; *Assessment Of Pollution Status And Vulnerability Of Water Supply Aquifers Of Keta, Ghana*. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Boukari, M., Azonsi, F. and et Abdoukarim A. (2005) *Using Drastic Method To Assess The Groundwater Vulnerability Of The Shallow Aquifer Of Cotonou City, Southern Benin* Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Bradbury, K.R. 2005; *Groundwater Protection Zoning: Background, Development, And Application In Porous, Fractured, And Karst Media* University of Wisconsin-Extension. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Chave P., Howard G., Schijven J., Appleyard S., Fladerer F., Schimon W. (2005) World Health Organisation document in preparation- Chapter 17 http://www.who.int/water_sanitation_health/resourcesquality/en/groundwater17.pdf

Chilume, C. 2005 *Groundwater Pollution Hazard From Cattle Burial Sites, Ngamiland District, Botswana*. Botswana Geological Survey, Lobatse. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Cobbing, J. 2005 *Cryptosporidium and Scottish Groundwater Protection Zones* CSIR Pretoria. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

El Arabi, N. 2005 *The Egyptian Research Institute for Groundwater*. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

IWGP-Legal Group, 2005 Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Jolly, J.L. and Reynders, A.G. (1993) The protection of Aquifers: A proposed classification and protection zoning system for South African conditions. An international Groundwater convention entitled 'Africa Needs Groundwater' at the University of the Witwatersrand, Johannesburg, South Africa, 6-8, September 1993.

JOURDA Jean Patrice R. *Joint Management of Transboundary Coastal Aquifer Resources in the Gulf of Guinea: Preliminary Transboundary Diagnostic Analysis (TDA)* Universite De Cocody - Abidjan. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Liu, D. 2005 *Groundwater protection in China.* Southwest Jiaotong University, Chengdu, China. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Lupimo, N. 2005; *The Impact Of Urbanisation On Groundwater Resources: The Tanzania Case*. Presentation at the International Workshop on Groundwater Protectiontection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Massone, H. and Sagua, M. 2005 *The Integration Of Social Vulnerability In The Groundwater Pollution Risk Assessment.* Universidad Nacional de Mar del Plata. Argentina. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Mbatha, C.N. 2005 *The Economic Valuation of Groundwater Resources*. Rhodes University, Grahamstown. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Mwango, F.K. and Githae, I.T. 2005 *Groundwater Protection In Kenya -Wajir Town Case Study.* Ministry Of Water And Irrigation – Kenya. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Nel J.M. and Xu, Y. 2005 *Development of a policy on Protection Zoning for South Africa* University of Western Cape, Cape Town. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Nel, J.M. and Bishop, R. 2006 *Strategic Use of Groundwater In Cape Town, South Africa.* University of Western Cape, Cape Town. Presentation at the Fourth World Water Forum, 16 -24 March 2006, Mexico City.

Nkhuwa, DCW, Nyambe IA, Tembo JM, Chikama G, Chola P, Kang'omba S, Silembo O, and Mpamba NH (2005) *Vulnerability Of Water Supply Aquifers In Lusaka – A Case For John Laing & Misisi Townships.* Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

National Water Quality Management Strategy (NWQMS) (1995) Guidelines for Groundwater Protection in Australia. Department of Pimary Industies and Energy, Agriculture and Resource management Council of Australia and New Zealand. Canberra.

Pienaar, H. 2005 *Water Resource Protection in South Africa* Department of Water Affairs and Forestry, South Africa. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Pool E. 2005 Personal Communication

Pool, E. 2005; *The Impact Of Water On Human & Animal Health.* Medical Bioscience, UWC. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Robins, N. and Chilton, J. 2005 *Adapting Experience From The Uk To Africa: Vulnerability And Groundwater Protection* British Geological Survey. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Robins, N. and Chilton, J. 2005. *Adapting Experience from the UK to Africa: Vulnerability and Groundwater Protection.* British Geological Survey. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Seynabou, C.F. 2005 *Assessment Of The Thiaroye Aquifer Intrinsic Vulnerability Using Drastic And God Methods* University C. A. D. Dakar Senegal Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Taylor, R., Cronin, A., Pedley, S., Barker, J., Atkinson, T. (2004) The implications of groundwater velocity variations on microbial transport and wellhead protection- review of field evidence. FEMS. 49 17-26.

Tredoux and Colvin, 2005 *Groundwater Nitrate in the Rural Setting and its Social Impacts* CSIR Stellenbosch. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Usher BH; Pretorius JA; Dennis I; Jovanovic N; Clarke S; Cave L; Titus R; Xu Y (2004), Identification and prioritisation of groundwater contaminants and sources in South Africa's urban catchment. WRC report 1326/1/04. Pretoria.

Usher, B. 2005 *Assessment Of Pollution Status And Vulnerability Of Water Supply Aquifers Of African Cities: What Was The Impact ?* Institute for Groundwater Studies, Bloemfontein. Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Vogel, H. 2005 *Groundwater Quality Case Studies in Botswana*. Botswana Geological Survey, Lobatse Presentation at the International Workshop on Groundwater Protection for Africa, 28-30 November 2005, University of the Western Cape, Cape Town.

Wyoming Department of Environmental Quality (WDEQ) (2001) Wyoming's Source Water and Wellhead Protection Guidance Documents. Document URL: http://www.wrds.uwyo.edu/wrds/deq/deq.html