**CAN GROUNDWATER SUSTAIN THE FUTURE DEVELOPMENT OF RURAL ZIMBABWE?**

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Abstract

Zimbabwe occupies a tectonically stable plateau underlain by ancient Precambrian crystalline basement rocks. These form a central craton bounded by east-west trending mobile belts; the Zambezi mobile belt to the north and the Limpopo mobile belt to the south. Zimbabwe receives generally low and variable quantities of seasonal rainfall within a semi-arid to savannah type climate characterised by moderate to high temperatures. Evaporation commonly exceeds rainfall so that recharge to the thin near surface aquifers is generally low and in some years non-existent. The groundwater resources of the weathered and fractured basement aquifers that underlie more than 60% of the country are of limited potential, typically sufficient to supply the needs of small villages and cattle ranches. However, within the central plateau area of the African to Post-African erosion surfaces, the weathered and fractured basement may exceed 60 m in thickness. The thickness of this zone diminishes towards the main valley systems where subsequent cycles of erosion have stripped the weathered zone away leaving only a shallow surface fractured zone that may only be 20-30 m thick. Groundwater resources have been developed extensively in Zimbabwe since the 1920s. During the 1991-92 drought abstraction from urban boreholes within the southern Harare area caused yield decline and ultimate failure of numerous boreholes. It is now time to question the long-term viability of groundwater development within the basement aquifers in Zimbabwe given the uncertainty in groundwater resource, the complexities of the climate-groundwater interactions and the projected demands of a growing rural population.

1. IMPORTANCE OF GROUNDWATER TO ZIMBABWE

Zimbabwe, with a 12.5 million population is experiencing a national water crisis, especially the 73% who live in rural areas where access to safe, clean water supply is critical for survival. The rural population is dependent for much of the year on accessing safe drinking water mainly from low yielding Basement Complex aquifers. With as many as 60% of rural water pumps currently out of action an estimated 2.5 million people are deprived of safe water (Sokwanele, 2010). Groundwater is not only used for domestic supply but also for small scale garden irrigation (PHHEP, 2013). However, these low-yielding sources are susceptible to seasonal variation and yield decline and failure during prolonged drought.

Following independence, government prioritised provision of sustainable water sources to rural communities especially those affected by the 1982-1984 drought. During the period between 1980 and the mid-1990s more than 30 000 boreholes were drilled for drought relief, refugee resettlement and rural development keeping Zimbabwe on target to meet the Millennium Development Goal (MDG) to supply 80% of the rural population with clean water by 2015. With the impact of the post 2000 economic decline, funding for rural water point maintenance failed, leaving such maintenance as was possible to community based management schemes aided by NGOs. By 2003, there were 28 500 operating hand-pumped boreholes in Zimbabwe but a further 8600 were non-functional boreholes due
apparently to mechanical failure. In many cases communal water sources remained out of action for 10 years or longer (PHHEP, 2013).

Zimbabwe’s health and education statistical indicators were once the most favorable in Africa. During 1990-2003, deterioration in infrastructure caused an increase in the poverty rate from 25% to 63% (IFAD, 2013). Water is crucial for health and development as shown by the cholera outbreak in 2008 caused by a lack of access to clean water (MDP, 2008). In 1994, 95% of urban and 80% of rural populations had access to clean drinking water (UNICEF, 1994), mostly from groundwater. By 2000, although 99% of the urban population had access to clean drinking water, the rural per capita access rate had declined to 62% (UNICEF, 2000). By 2008, 51% of water collection points had failed putting the population at risk from cholera, hepatitis A, bacterial and protozoal diarrhea and typhoid fever (Osvald, 2008). By 2009, while 73% of the total population had access to clean drinking water only 61% of the rural population had access to reliable water, with 36% from boreholes, 18% from protected wells, 25% from unprotected wells, 11% from surface water and 10% from other sources (Zimbabwe National Statistics Agency, 2009).

2. PHYSIOGRAPHY

Geology and Geomorphology

Zimbabwe is a landlocked country bounded by Mozambique to the east, Zambia to the north, South Africa to the south and Botswana to the west. It lies between latitudes 15.5°S and 22.5°S and longitudes 25°E and 33°E and has an area of 390,759 km² (Figure 1). The country occupies a high-level plateau that forms a north east – south west trending watershed between two major eastward flowing drainage systems, the Limpopo to the south and the Zambezi to the north. Most of the country lies at above 1000 masl. The geomorphology of the country strongly reflects the underlying geology.

![Figure 1. Administrative Map of Zimbabwe (Source: UN Cartographic Section).](image)

The eastern boundary with Mozambique is marked by the Eastern Highland chain and the western boundary with Botswana by the fringes of the Kalahari Desert. Palaeozoic and younger-age mainly sedimentary rocks occupy the Limpopo valley and the down-faulted Zambezi rift. Lister (1987) recognised four geomorphological units:

- Eastern Highlands – the highest part of Zimbabwe at nearly 2600 masl.
- Limpopo-Sabi Lowlands – the Sabi and Limpopo valleys below 650 masl.
- The Zambezi Valley – A down-faulted rift valley.
- Central Plateau – A central area above 800 masl about a central NE-SW trending ridge

Lister (1987) correlated the altitude ranges of the features with flat-lying erosion surfaces recognised by Partridge and Maude (1987) in southern Africa (Figure 2):
- African surface along the water divides higher than 1000 masl
- Post African surface at 800-1000 masl
- Pliocene-Quaternary cycle of erosion terrain below 800 masl

The older the erosion surface the thicker and better developed the underlying weathered and fractured zones. The confluence of the central plateau and the peripheral lowland areas is marked by a zone of valley incision and scarp erosion where the weathered zone has been eroded to reveal characteristic granitic whalebacks or inselbergs with valleys developed along fracture zones (Romer, 2007).

The central tectonically stable plateau comprises an Archean central craton, 238 000 km² in area, bounded by east-west trending greenstone mobile belts; the Zambezi mobile belt to the north and the Limpopo mobile belt to the south (Stagman, 1981). The central craton includes Precambrian age crystalline basement complex granitic gneisses and schists with meta-sedimentary and meta-volcanic rocks. The mobile belts comprise E-W trending zones of schists, gneisses and amphibolites. The craton has little prominent faulting, apart from the N-S trending Great Dyke. The mobile belts are ancient zones of fracturing reactivated during rifting of the Gondwana continent.

**Climate and Hydrology**

Drought is a regular occurrence that has had a reoccurring and major impact in the country since the 1890s (Iliffe, 1990). Zimbabwe receives low quantities of seasonal rainfall within a semi-arid to savannah type climate characterised by moderate to high temperatures. Monthly rainfall records are available from 105 stations for 1920-1996. Rainfall between November and March occurs as short duration high intensity events mainly associated with depressions and cyclones originating in the western Indian Ocean (Figure 3) (Malherbe et al, 2012). Monthly evaporation records are available.
from 29 stations distributed throughout Zimbabwe. Evaporation commonly exceeds rainfall so that in most years there is only limited effective rainfall available to recharge aquifers.

Zimbabwe has seven major catchment areas. The Gwayi, Manyame, Mazowe and Sanyati rivers feed into the Zambezi Rivers while the Save, Mzingwane, and Runde rivers and the transboundary Shashe river feed into the Limpopo. Most tributaries are ephemeral and choked with water bearing sands that are dry season sources of water for domestic and small scale irrigation (Hussey. 2007).

3. GROUNDWATER IN ZIMBABWE

As evaporation greatly exceeds rainfall, recharge to the near surface weathered basement aquifer is intermittent to non-existent. Evaporation removes surface moisture causing decline in water levels in years of low rainfall or drought, as experienced during the 1991-1992 drought.

The groundwater resources of the weathered and fractured basement aquifers of Zimbabwe are of limited potential. Groundwater occurrence in Basement complex aquifers has been studied by Jones (1985), Wright (1992) and Titus et al (2009). Collectively, they describe the presence of groundwater within the near-surface weathered and fractured zones as reviewed by Taylor and Eggleton (2001).

The weathered and fractured basement below the African erosion surface may reach 60 m in depth in the central plateau, with borehole yields of 0.5-1.0 l/sec. The thickness of this zone declines towards the main valleys where the Post-African and the Pliocene cycles of erosion have stripped the weathered zone away to leave a shallow near surface weathered and fractured zone 20-30 m thick with borehole yields of 0.05-0.1 l/sec (Interconsult, 1985).

The weathered and fractured basement has low development potential as it is thin with low permeability, porosity and storage. The widespread distribution of this system throughout tropical and subtropical Africa, South America and India makes it the main source of domestic water for the majority of rural populations. Black and Talbot (2005) reported the large scale over-utilisation of this limited resource for irrigation that resulted in the lowering of water tables and reduced resource potential to rural populations in India, even with the reliable annual monsoon recharge (Marechal, 2007). Similarly, in Zimbabwe groundwater development continued to a point when the resource
became stressed. Borehole drilling increased progressively with time in Zimbabwe peaking in the late 1990s (Figure 4 and 5).

Figure 4. Rates of borehole drilling and population growth sustained during 1948-2010.

By 2003, there were 28,515 operating and 8668 non-functional hand pumped boreholes (PHHEP, 2013). Of the 17,233 listed in the ZINWA database some 14,577 records include location, date drilled, borehole depth, yield and lithological data. These data indicate that most boreholes drilled during 1976-1996 were into Basement Complex aquifers (Figure 5). However, availability of hydraulic data for Basement Complex aquifers remains poor; the National Water Master Plan (1986) found many borehole records contain unreliable data.

Figure 5. All Boreholes drilled and those in Basement aquifers, 1976-1996 (ZINWA, 1997).

4. THE GROUNDWATER RESOURCES OF ZIMBABWE RECONSIDERED

Although thousands of boreholes have been drilled in Zimbabwe, understanding the factors leading to water point operation or failure remains poor. The central borehole archive contains data and information submitted by drilling contractors and project consultants. Government institutions have lost the capacity to collect information during borehole drilling and testing supervision resulting in a marked decline in data quality control. Those involved with the development of groundwater resources depend upon the National Water Master Plan of 1986 for information (Robins et al, 2006).
Paradoxically, this negatively impacts upon the next National Water Master Plan as there is a retained lack of data. A similar situation in Uganda and Malawi led to the conduction of country-wide censuses of water points, noting the GPS location of boreholes, wells springs and standpipes and information on pump type, pump status, and plinth data e.g. borehole number and date installed. The survey data collected were used to accurately locate boreholes, link to data held in the National Borehole databases, and enable updated assessments of groundwater resources status (Ministry of Water, Lands and Environment, 2001; Robins et al, 2013). This concept could usefully be applied in Zimbabwe.

There is an almost total lack of long-term groundwater level monitoring available to assist the estimation of groundwater recharge in Zimbabwe. Potential recharge to weathered and fractured Basement Complex aquifers based on long term decadal wet/dry periods, thought to reflect sun spot cycles, have been proposed (van Wyk et al, 2011). Robins et al (2013) have assessed the sustainability of the groundwater resources of weathered and fractured basement complex aquifers in Malawi and question the long-term viability of Basement aquifers there. While the sustainability of the groundwater resource in Zimbabwe has been questioned (e.g. Chikodzi, 2013) by application of GRACE data to provide indications of current low water levels, this assessment lacks the necessary long-term data as GRACE data have only been available since 2004.

To obtain some indication of potential recharge in southern Zimbabwe, monthly rainfall data from Masvingo matched with tropical storm and cyclone data from Malherbe et al. (2012) (Figure 3) were correlated with composite groundwater level data from Limpopo Province in South Africa (Department of Water Affairs, South Africa), the Romwey Catchment in Masvingo Province (Lovell et al, 1998) , and sites in Malawi (Ministry of Water Development and Irrigation, Malawi) (Figure 6). The data suggest that such high intensity storm systems offer a mechanism for overcoming the high background evapotranspiration rates recorded in the drought prone areas to provide recharge to basement complex aquifers. Marked increases in water levels, of the order of 5-10 m, are caused by recharge from intense storm events, consistent with the observations of Taylor et al (2012) in Tanzania, and records from the Sahel region and southern Africa compiled by Scanlon et al (2006). During prolonged periods of little or no recharge, there is a consistent rate of water level attenuation, of 0.5-1.0 metre per year that can result in water levels falling below the zone of normal water table fluctuation in the lower coarser saprolite zone (Figure 7).

![Figure 6](image)

Figure 6. Correlation of groundwater levels movement in response to drought conditions and tropical storm and cyclone events (Department of Water Affairs, South Africa; Lovell et al, 1998; Ministry of Water Development and Irrigation, Malawi, and Louvain University, 2013).
Groundwater occurrence in the shallow weathered and fractured zones developed within granitic and gneissic basement complex rocks has been studied in many diverse places including India, Jersey, Brazil and Zimbabwe (Davies et al. in press). There is a common pattern of weathering with the development of an upper saprolite zone with increasing permeability with depth associated with the granular and fractured weathering below which only fracture permeability is present (Figure 6). In Zimbabwe, the upper higher permeability zone is developed only to 10-20 m depth. Boreholes drilled using down-the-hole-hammer equipment penetrates through this zone into the fractured aquifer beneath, developing the lower permeability zone (Davies et al. in press).

![Diagram of groundwater flow](image)

Figure 6. Flow to and within the weathered/fractured saprolite zone. The low permeability fractured zone lies beneath the weathering front.

The poor understanding of the impact of drought upon groundwater systems reflects an overall lack of groundwater level monitoring data, poor understanding of groundwater occurrence in low permeability basement complex aquifers and poor understanding of the recharge processes associated with intense but irregular tropical storms.

Village water supply systems from low permeability sources have finite potential. A study of water supplies in Gwanda district, southern Matabeleland, by Dube (2013) reported that:

- 60% of households travelled more than 0.5 kilometres to fetch water; some households travel 5 to 8 km, when the maximum distance to the nearest water point should be just 500 m. Most of these local boreholes had either broken down or were dry due to lowered water tables.
- Most boreholes and protected wells were in a serious state of disrepair.
- The average water usage is 13.1 l per person per day whereas the minimum recommended is 15 litres per person per day.
- An average of 945 people use each borehole against the recommended 250 people per borehole.

Observations made during the 1982-84 and 1991-92 droughts indicate that shallow hand dug wells dry up and borehole yields decline and sometimes fail. These observations indicate that the resources of the basement complex aquifers appear to be severely depleted due to normal abstraction during droughts causing water level decline into the lower permeability fracture zones. These impacts would become more prevalent with increased demand from a rapidly growing rural population.

The Zimbabwe situation is similar to Malawi where a large number of boreholes have been drilled to meet the water demands of a rapidly expanding population. Records exist for only a fraction of boreholes installed within Malawi and there is no indication of how many boreholes have failed or of
the cause of failure. As a precursor to the on-going National Water Master Plan project a Water Resources Investment Strategy (Atkins, 2011) was prepared that included an assessment of the present groundwater resources of Malawi (Robins et al, 2013). This study assessed for each sub-catchment whether there was sufficient recharge to replace:

- Groundwater abstraction.
- Throughflow due to natural attenuation.
- Water pumped from storage.

Information required to make the assessments includes:

- Long-term monitored groundwater levels.
- Monthly rates of rainfall and average monthly evaporation.
- Census of water abstraction points especially boreholes and wells.
- Estimates of water quantities abstracted.
- Estimates of thicknesses of weathering, saturated thickness and transmissivity.
- Groundwater gradients and sub-catchment width.
- Soil and landform distribution to estimated areas of potential recharge.

Water Resource Areas or catchments were subdivided into weathered basement, fractured basement and alluvial areas. Volumes of groundwater throughflow and storage were calculated for each sub-catchment and related to total rates of groundwater abstraction to reveal several areas in danger of borehole failure due to groundwater mining of storage.

A similar analysis is required for the Basement Complex aquifer system in Zimbabwe where annual rainfall quantities are lower than those experienced in Malawi. The results might explain why borehole yields declined during the 1991-92 drought leading to borehole failure in southern Harare. Such images have been mirrored in southern Zimbabwe where numerous boreholes in the Limpopo valley have failed. The causes of failure may be due to groundwater resources limitation rather than mechanical failure, yet the true underlying causes cannot readily be assessed due to data scarcity, particularly long-term hydrographs.

6. CONCLUSIONS

Significant amounts of historical information and older data are available within Zimbabwe to improve on the understanding of the nature and resources of Basement Complex Aquifer provided by the National Water Master Plan of 1986. More than 30 000 boreholes may have been drilled in Zimbabwe since the last Master Plan was produced. As in Malawi and Uganda, a prerequisite for the production of an updated Water Master Plan is a national water point survey that includes the accurate location and status of boreholes wells and springs as well as standpipe locations.

The water resources situation in Zimbabwe requires the establishment of an effective groundwater monitoring system, based, for example, upon the system presently operating within the Limpopo Province of South Africa (Chikodzi 2013). Effective groundwater resource management needs also to include the accurate correlation of rainfall events with groundwater level shifts within rural areas. In urban areas, such data need also need to be related to the frequent periodic water quality deteriorations, to seek to be able to provide early warning of potential pollution problems and avoid incidences of cholera and typhoid.

Application of GRACE technology in Zimbabwe has produced the realisation that “groundwater levels in most parts of Zimbabwe’s catchments are in a state of decline. Most of the catchments have average groundwater levels marginally above their long-term means except for the Zambezi Valley which now shows a negative long term trend” (Chikodzi, 2013). This conclusion mirrors that produced from analysis of the composite water level graphs from Zimbabwe, Malawi and South Africa. The GRACE data are as yet short-term and is not available for analysis of the impact of the
1991-92 drought and the rate of recovery of water levels. This technology will be of great use in the future but can only be used effectively when correlated with borehole monitoring data.

It is now time to question the long-term viability of groundwater development within the basement complex aquifers in Zimbabwe given endemic drought, uncertainties in the groundwater resources potential and the rising rural population. The reasons for borehole failure need to be better understood; are the failures due to mechanical failure, changes in climate and land use, resource depletion or a complex combination of all these?

The rates of aquifer depletion in the absence of rainfall recharge events and the rate of aquifer recovery following droughts as well as the importance of tropical storm/cyclone activity to the latter needs to be fully understood if drought mitigation methodologies based upon groundwater abstraction systems are to be fully effective.

The question has to be asked: can groundwater provide an effective sustainable resource for the future development of rural Zimbabwe?

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