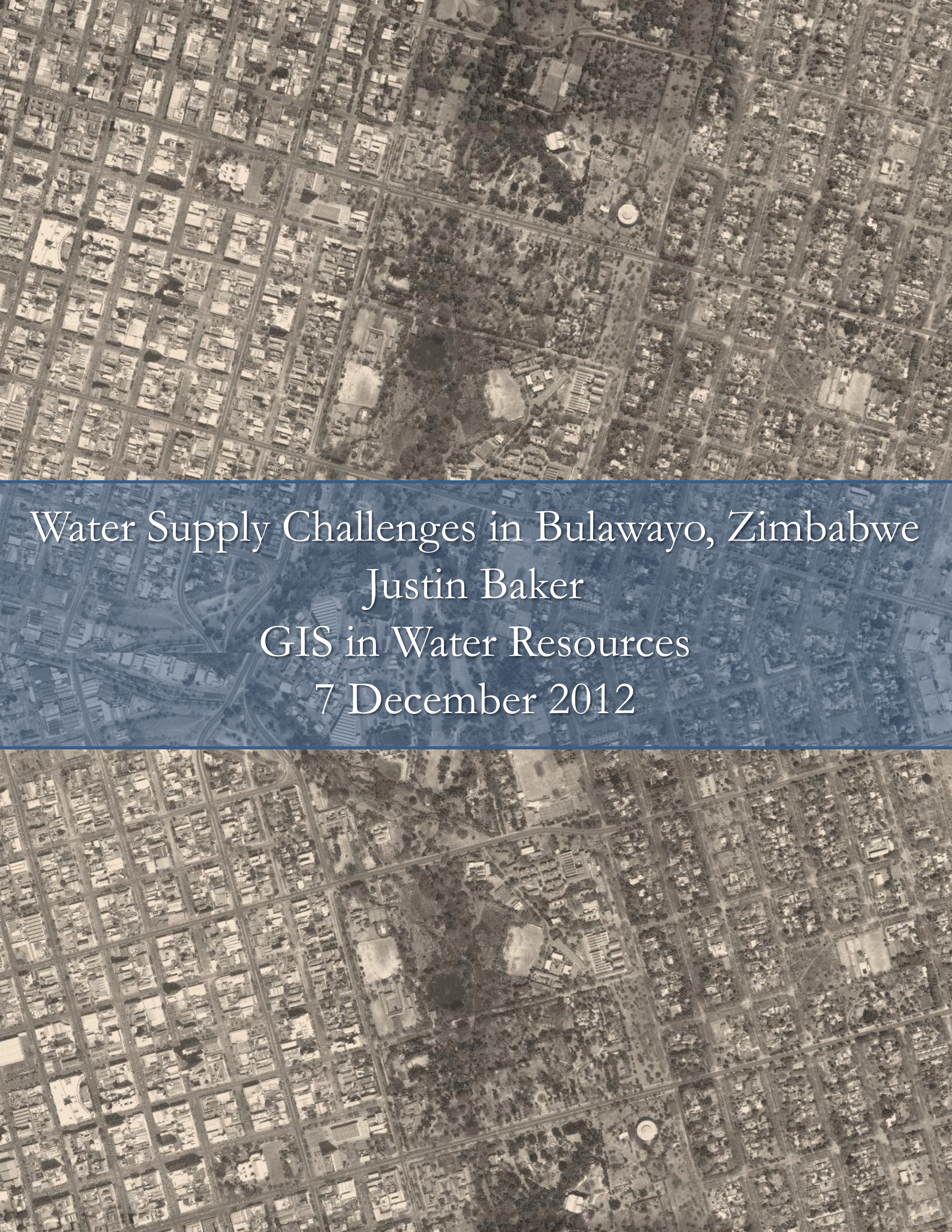


Water Supply Challenges in Bulawayo, Zimbabwe

Justin Baker

GIS in Water Resources

7 December 2012

1. Introduction

1.1 Why Bulawayo?

In September 2012, the Bulawayo City Council (BCC) implemented a new policy: all households in the city connected to the municipal sewage system would be required to flush their toilets simultaneously twice each week (BBC, 2012). This was done to keep pipes from becoming blocked and damaged, currently a threat due to severe water restrictions in place by the city (often for three days at a time).

Figure 1

Yet to residents of Bulawayo, this mandate was not surprising. The city of Bulawayo has struggled to secure sustainable and long-term water resources for its citizens for over one hundred years. The water stress currently faced by the city, like that before it, can be attributed to several factors, including economic decline, geographic location, and climate effects.

Bulawayo, therefore, is a good case study of the challenges of water supply in urban Africa for at least three reasons: it is growing rapidly (in line with other cities), it has a great need for water at present, and it already has a relatively developed infrastructure system in place.

1.2 Water Supply in Africa

Worries over water supply in Bulawayo is only part of a larger trend across urban Africa (Economist, 2010). Water is vital to any development, and its availability or dearth is a major driving force behind migration, population growth, and economic development, among other factors. As a whole, Africa has relatively ample water supply potential (MacDonald and Calow, 2009, p. 2). The per capita availability of water in Africa is on par with Europe and above Asia, yet the African struggle is much greater than that of most other parts of the world.

Still, there are two Africas – the rural Africa, mostly dependent on subsistence agriculture; and urban Africa – a fast-growing population in cities. Both of these populations require water for development, and solutions must be tailored to their needs. One of the most ambitious goals laid out by the United Nations in their Millennium Development Goals is "halving, by 2015, the number of people without access to safe water and sanitation" (United Nations). The Economic

Commission of Africa set its own goal, to create "an Africa where ther eis an equitable and sustainable use and management of water resources for poverty alleviation, socio-economic development, regional cooperation, and the environment" (UN Economic Commission for Africa) This report concentrates on urban water supply, in a specific context, with the hope of drawing out broader conclusions applicable to other urban contexts across the continent.

1.3 Scope of Study

This paper is divided into three sections, roughly corresponding to an examination of the demand, current and future supply options available to the city, and some comments on the applicability of GIS techniques in this specific setting. The first will briefly outline the struggle for a reliable water supply that has faced Bulawayo for decades, presenting pressure factors such as population growth, economic decline, political favor, and climatic and environmental factors. Some comments are also made concerning future demand projections.

The second section will detail the current supply of the city, with a focus on the surface water sources that the city possesses, and move on to evaluate a potential future option, the Matabeleland Zambezi Water Project. GIS techniques will be employed to compare the old and new watersheds using remotely sensed and climatic data, in an attempt to understand the shortcomings in the city water supplies and glean lessons from past plans. Some comments are then made on the feasibility of the project.

The paper concludes with a short discussion on the potential uses and limitations of GIS techniques in Zimbabwe, and in data-poor Africa more generally. This section highlights the usefulness of remotely sensed data, especially useful in research, planning, and design.

2. Demand in Bulawayo

2.1 A Thirsty City

Beginning in 1980, Bulawayo saw an unabated increase in water demand over the past three decades, with increasing urbanization, economic activity (until 2000), and population growth generally contributing to the rise.

The city was founded in the 1840s, and today is the second largest city in Zimbabwe. Its economy has developed around its position as an important regional transportation hub and center of industry. The city has, until very recently, undergone a sustained period of decline under a hastily-implemented land reform program leading to the loss of international credibility. Still, the city has a relatively well-developed infrastructure system, relative to other African nations.

As the capital of Matabeleland, home to most of Zimbabwe's minority ethnic group – the Ndebeles - Bulawayo is also the stronghold of the Zimbabwean opposition political party (MDC). Accordingly, some have claimed that it has been marginalized in the past, specifically due to its tribal and political affiliations (Karimakwenda, 2012). Yet throughout its history, whether under a colonial administration or the current government, Bulawayo has struggled to supply its citizens with adequate water.

Much of this has shortage has to do with climatic factors. Bulawayo has an average annual rainfall of just 590mm, and is in one of the hottest and driest parts of the region. The city is located very near the confluence of four distinct hydrobasins (Zambezi and Limpopo being the closest, as shown in Figure 1).

2.2 A Growing Population

The population of Bulawayo has steadily increased over time, to around 700 000 (2009), in line with urban areas across Zimbabwe.

The charts below (Figures 3,4) show the trend of water demand and supply from 1980 to 2010. The shortage has reached at least 15 million cubic meters, and is only expected to grow (Mkandla, Van der Zaag, & Sibanda, 2005). It should be noted that these figures are under the demand management conditions (including rationing and restrictions) that the city already has in place.

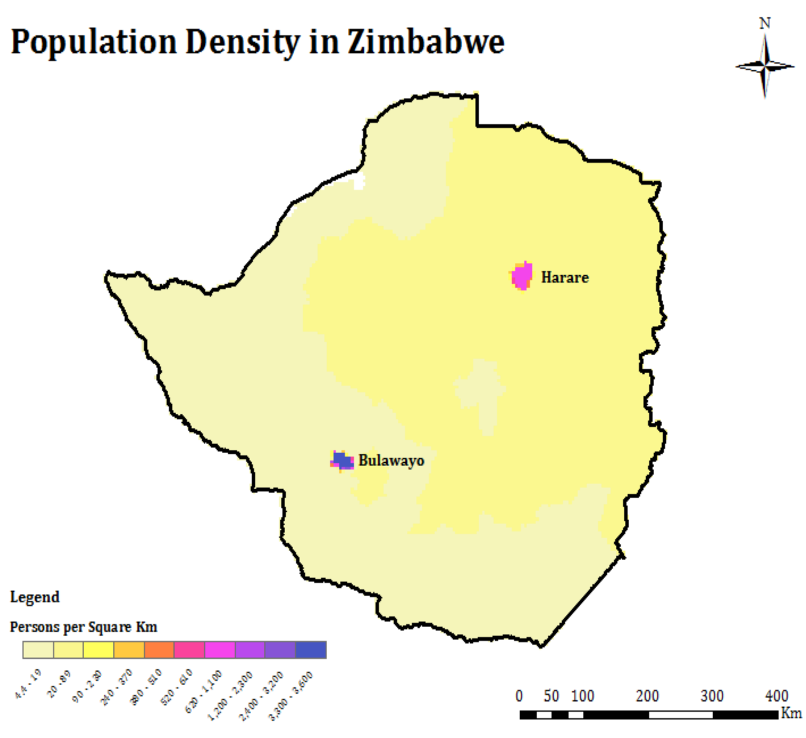


Figure 2

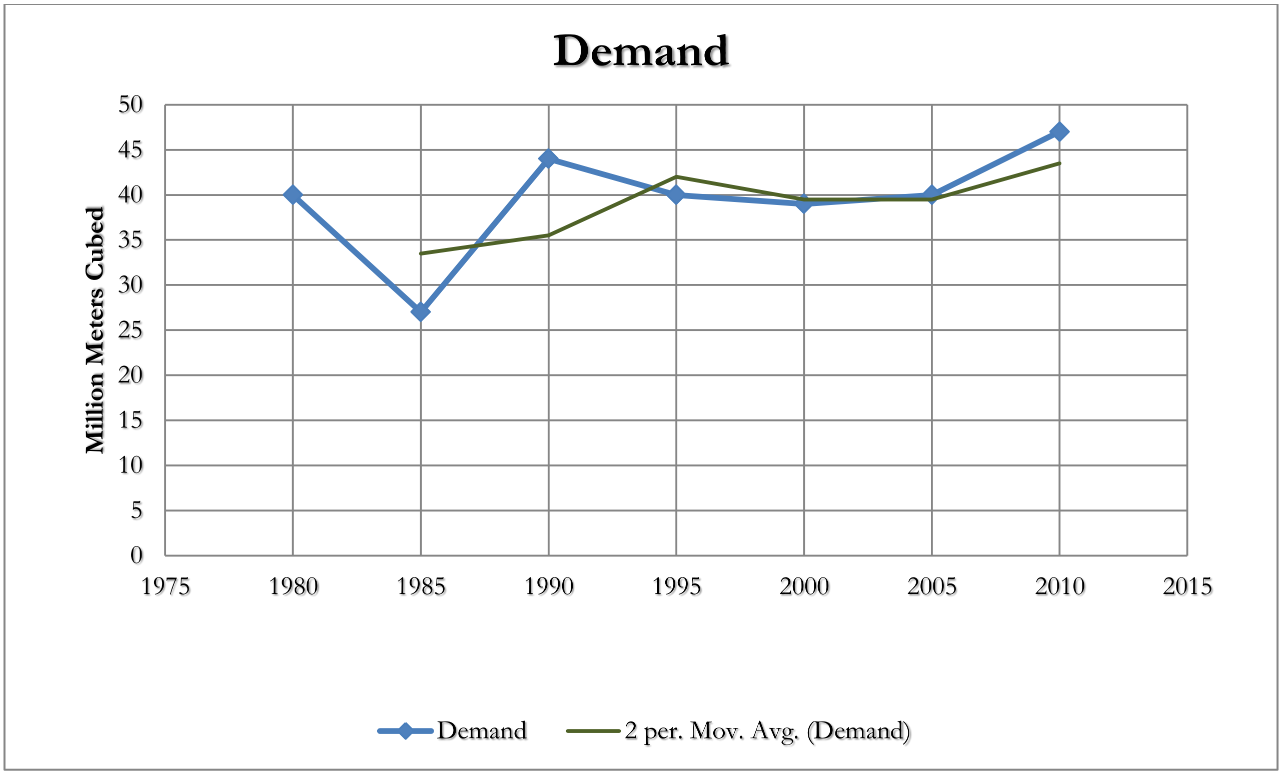


Figure 3

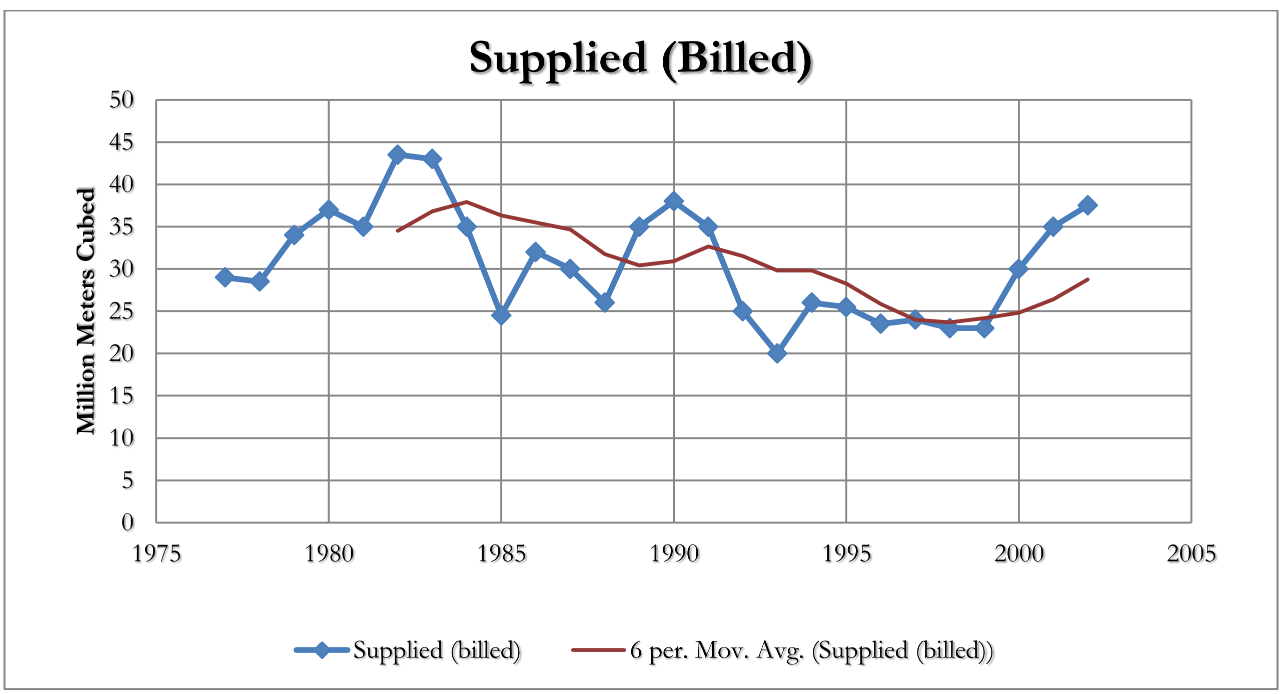


Figure 4

2.3 Future Demand

Future demand is expected to continue to grow, in step with general population growth and urbanization. Even the most intense demand management program will not be able to keep demand from growing by at least 15 percent, shown below in Figure 5 (Mkandla, Van der Zaag, & Sibanda, 2005). A new supply source is required, and this need will only grow in the future if it is not addressed.

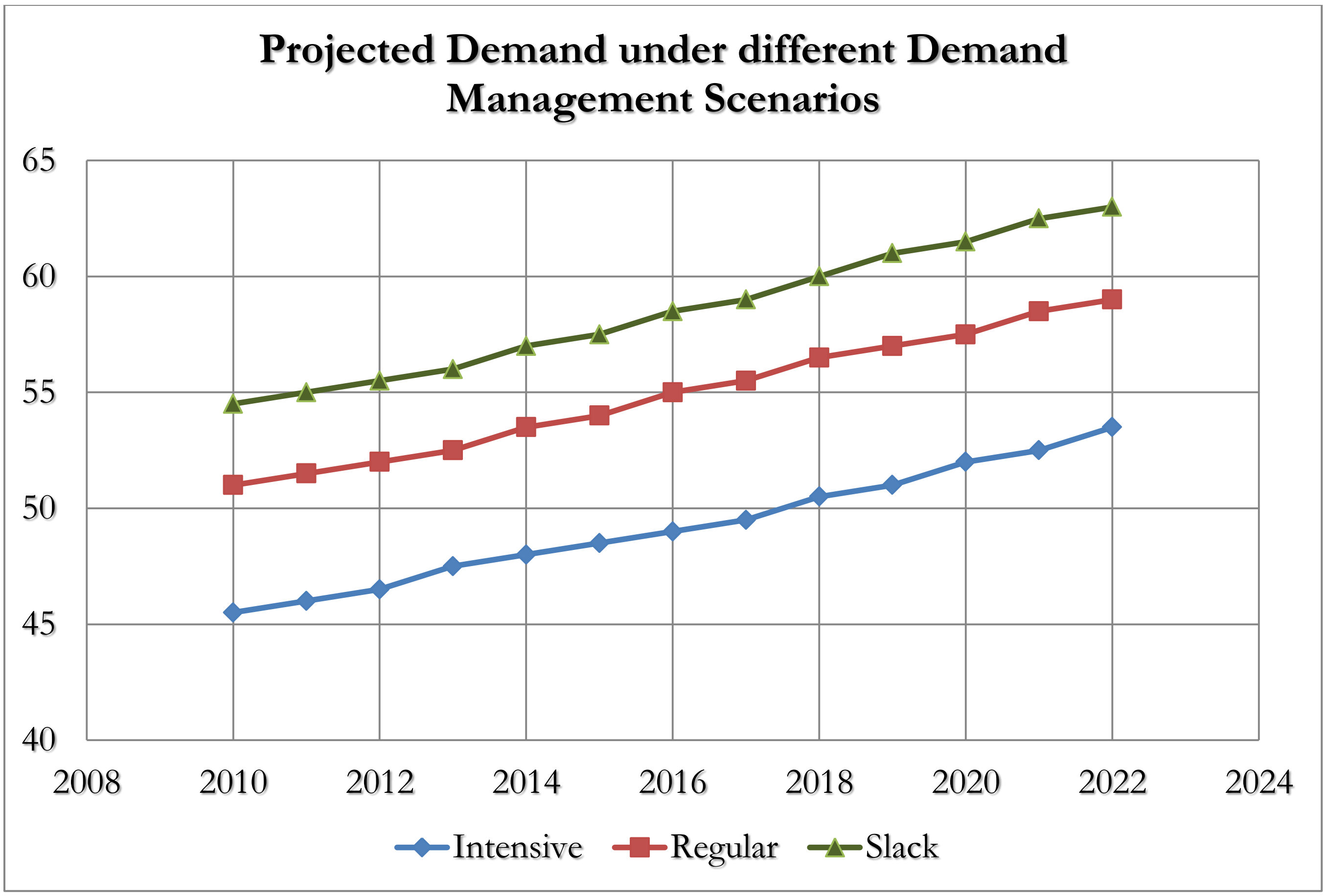
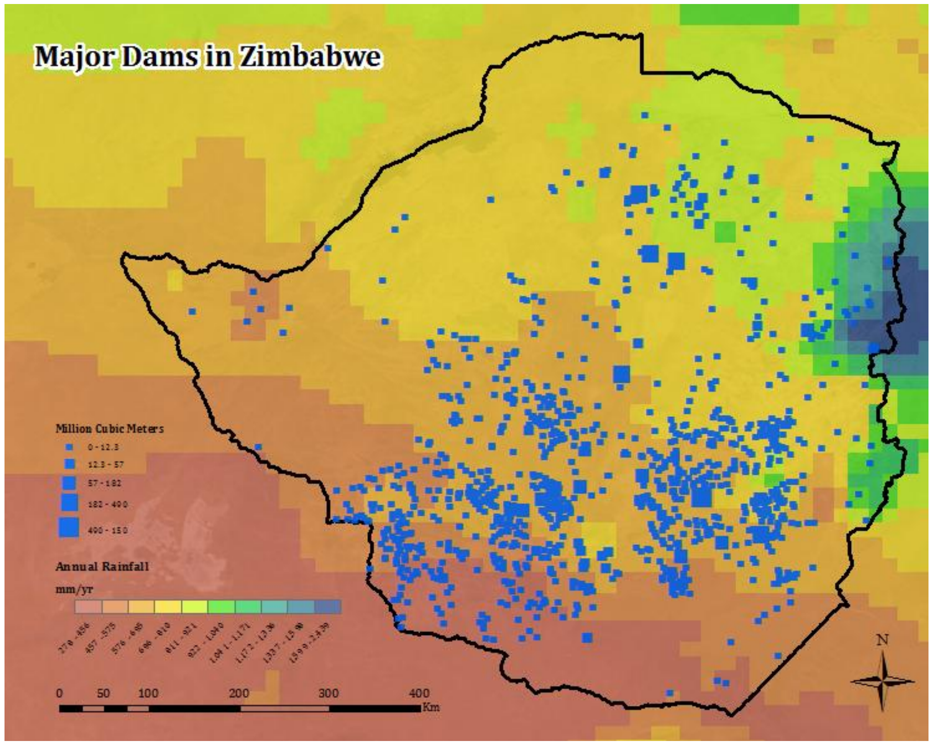


Figure 5

3. Current Water Supply

3.1 Dams in Zimbabwe

Figure 6



Zimbabwe is a nation of dams. It has over 10 000 dams currently, and more per capita than its regional neighbors. Dams have been relied upon to provide water for Zimbabwe's historically strong agricultural sector. Though this sector has been badly affected by recent government policies and lack of investment, the infrastructure of the country is largely intact. All major urban areas are supplied almost exclusively from dam water. As seen in Figure 6, the dams are largely spread through the drier parts othe country, where they are used to store water for agriculture. These dams can have a great impact on the watershed in which they are built.

Figure 7

3.2 Bulawayo's Supply Dams

Bulawayo has traditionally been supplied by five dams, built between 1958 and 1992. However, currently the city relies on only two of the five dams, the Inyakuni and the Insiza dams; the other three have been decomissioned (Figure 7 shows Umzingwane, decomissioned in 2012) (Makiwa, 2007). All of these dams are within 50 km of the city.

Supply from the dams has generally declined, due to drought and decreased runoff. For example, Figure 8 shows the number of days without flow at Insiza dam over time. The general trend is not encouraging (Onema, et al.):

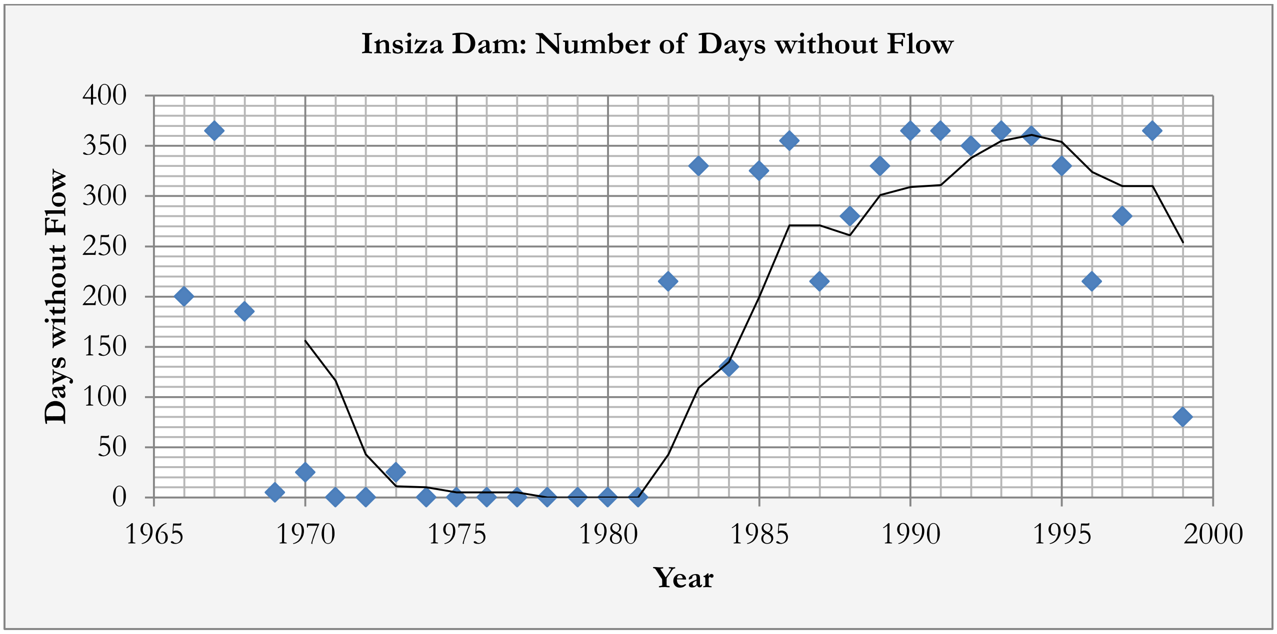


Figure 8

3.3 Future Supply

All parties to the discussion on water in Bulawayo agree on the fact that Bulawayo needs another substantial water supply option within the next five years, if not sooner (Mkandla, Van der Zaag, & Sibanda, 2005). Three options have been proposed:

1. *Boreholes* – This is a viable short-term solution, but boreholes are difficult to regulate, require maintenance, and the amount of water they can pump is uncertain.

2. *Bringing water in from the Zambezi by train* – This is not a feasible option.

3. *Build a new supply dam* – Under the Matabeleland Zambezi Water Project. This option is the most likely at present, and is the focus of the rest of this paper.

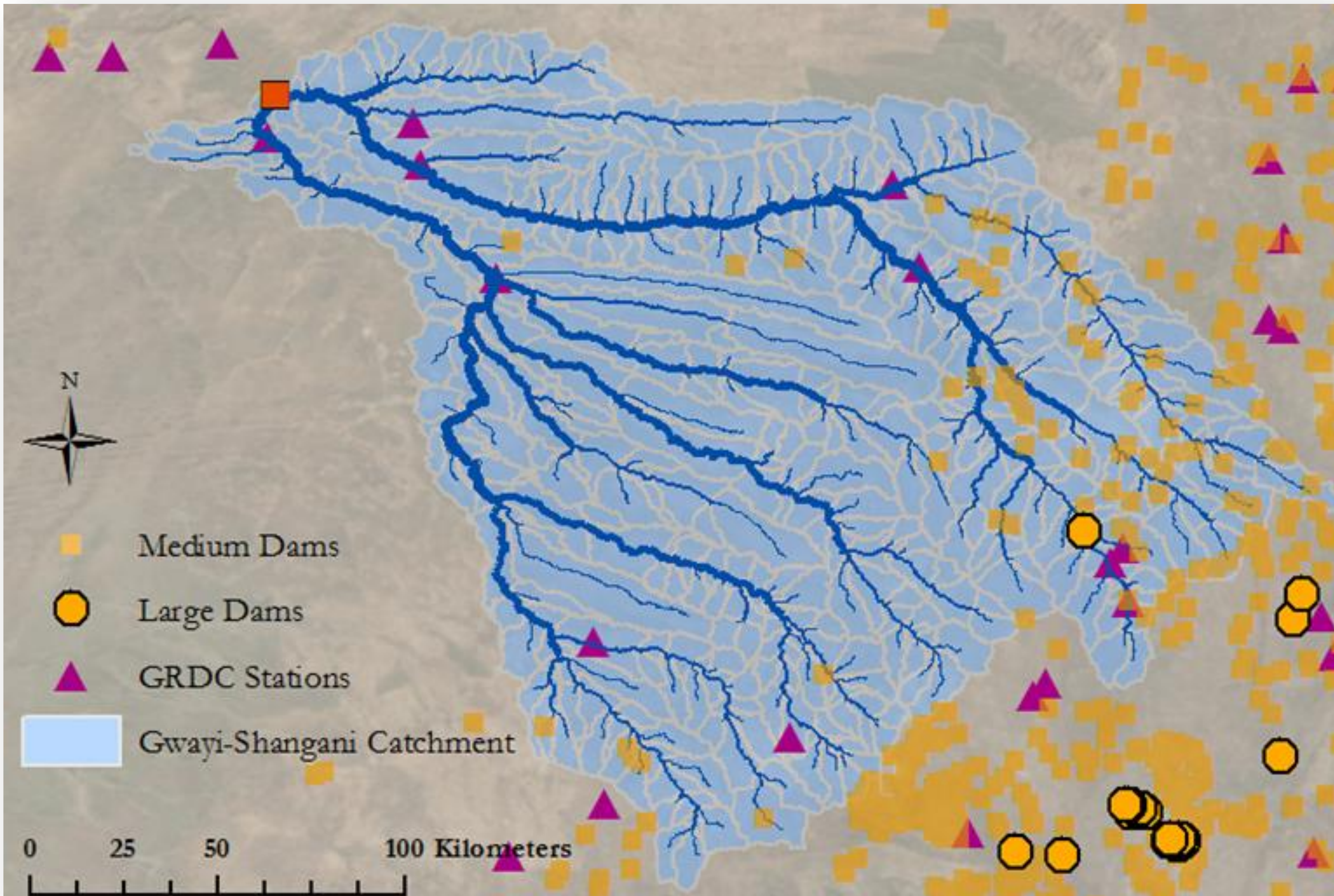


Figure 9

3.4 The Matabeleland Zambezi Water Project

The National Matabeleland Zambezi Water Project (NMZWP) proposes diversion of water from the Zambezi River 400km north of Bulawayo. It has been planned for over 100 years, and the current proposal involves three stages, involving a dam and pipeline construction (approximately 150km from city). Funding for the dam (approximately US$800 million) has recently been secured from the Chinese government, finally making the NMZWP a realistic possibility (New Zimbabwe, 2012).

The first and most urgent phase of the project is to construct a dam just downstream of the confluence of the Gwayi and Shangani rivers. This dam site is shown in Figure 9 above. The dam would then supply the city by pipeline, in much the same way as its five supply dams have done in the past over a shorter distance.

4. Methodology and Analysis

This section attempts to use standard GIS techniques to describe relevant characteristics of both the watershed that the city currently relies upon (Current WS) as well as the proposed Gwayi-Shangani dam watershed (Proposed WS). Comparing characteristics of the watersheds allows a measure of the effectiveness of the plan to build the new dam. Learning from past experiences with water resource planning is key, particularly in this unpredictable environment.

Most of the techniques relied upon work with a 90 meter Digital Elevation Model (DEM), obtained from ASTER (http://asterweb.jpl.nasa.gov/). The following sections describe the GIS analysis performed and results obtained for each parameter examined. This analysis used GIS data from the following sources.

4.1 Data Sources

FAO African Water Resource Database (AWRD)

- Most of the climatic data used came from this database, the best source of information on African water resources for GIS.

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)

- Digital Elevation Model: four squares were used to create a composite mosaic of Zimbabwe.

I. Precipitation

Using 30 year average annual rainfall values and a polygon reference shapefile obtained from the AWRD, average rainfall for each watershed was obtained using the Zonal Statistics Tool in ArcGIS.

Precipitation	Current Watershed	Proposed Watershed
Total	635mm/yr	633mm/yr

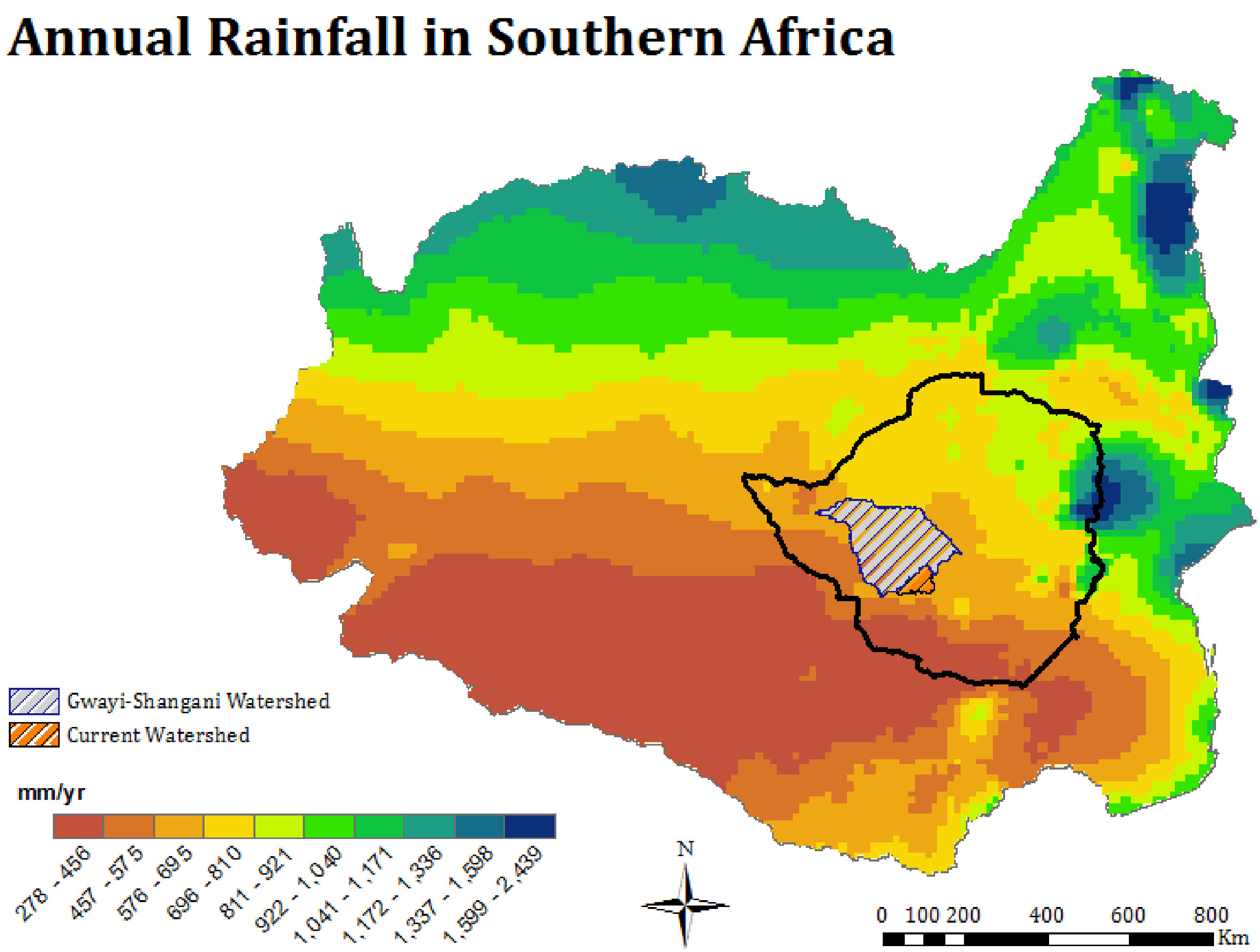


Figure 10

II. Evapotranspiration

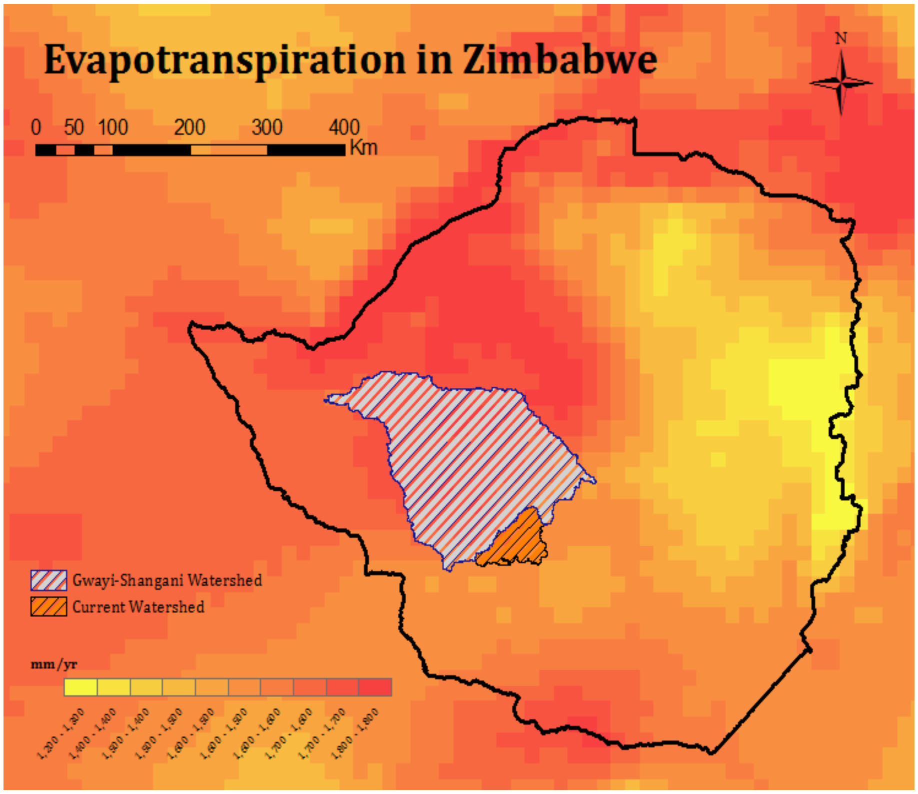


Figure 11

As for precipitation, an Evapotranspiration raster was used to calculate zonal statistics and assign them to each watershed. The results are summarized below:

Evapotranspiration	Current Watershed	Proposed Watershed
Total	1577mm/yr	1631mm/yr

III. Area

Area was calculated using the built in ArcGIS geometry tool. This was checked against the flow accumulation raster calculated for each watershed, and the numbers were nearly identical (when multiplied by the area of each grid cell, approximately 8100m2). The Proposed WS is much larger (more than ten times) than the one currently in use.

Area	Current Watershed (km2)	Proposed Watershed (km2)
Upper Ncema	612	
L Ncema	64	
Umzingwane	465	
Inyakuni	343	
Insiza	1810	
Total	**3294**	**36810**

Multiplying these areas by the average annual rainfall gives the annual available water (before evapotranspiration, runoff, etc). Again, there is a multiple of ten difference between the two watersheds:

Available Water	Current Watershed	Proposed Watershed
Total	2.09 km3/year	23.30 km3/year

IV. Runoff

Runoff is perhaps the most difficult parameter to obtain or calculate in this data-poor region. Below is a map of the relevant watersheds as well as the locations of GRDC stations around them (Figure 12). However, the GRDC data for these stations, where available, is only current up to 1990 at best. Much of the data available ends at 1980 records. This means that useful historical analyses can be performed, but current trends are more difficult to analyze.

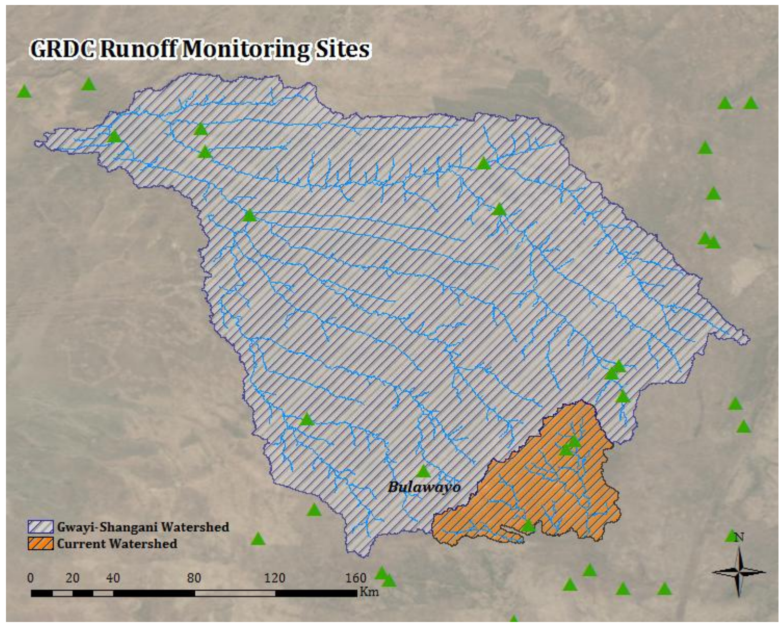
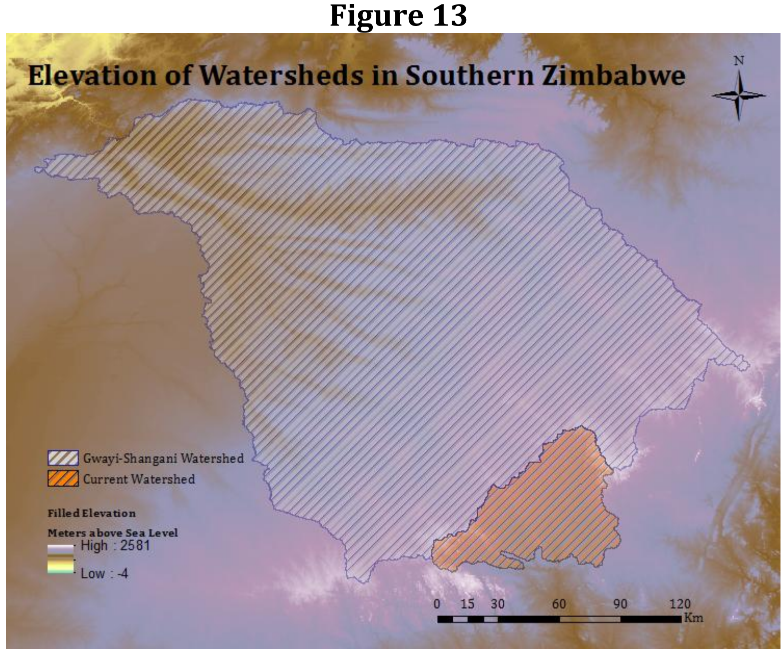


Figure 12

V. Elevation

As mentioned previously, Bulawayo sits on some relief, meaning that water generally tends to flow away from the city (to the south towards the Limpopo, or to the north towards the Zambezi). The average elevation values for each relevant watershed are shown below (Figure 13):

Figure 13



Elevation (meters above SL)	Current WS	Proposed WS
Mean	1278	1176
Max	1530	1527
Min	1079	880
Range	451	647

These values are expected, as the Proposed WS covers a much greater area as it moves water down towards the Zambezi.

VI. Slope

Though the Proposed WS has a greater range of elevation, the Current WS actually shows the greatest slope, shown below (Figure 14):

Slope (degrees)	Current WS	Proposed WS
Mean	2.64	1.20
Max	35.8	29.2
Min	0	0

Figure 14

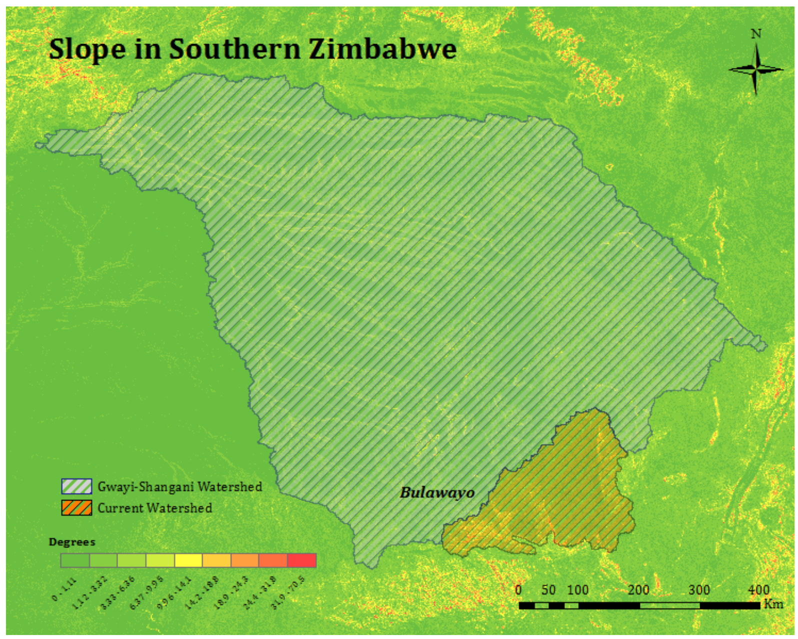
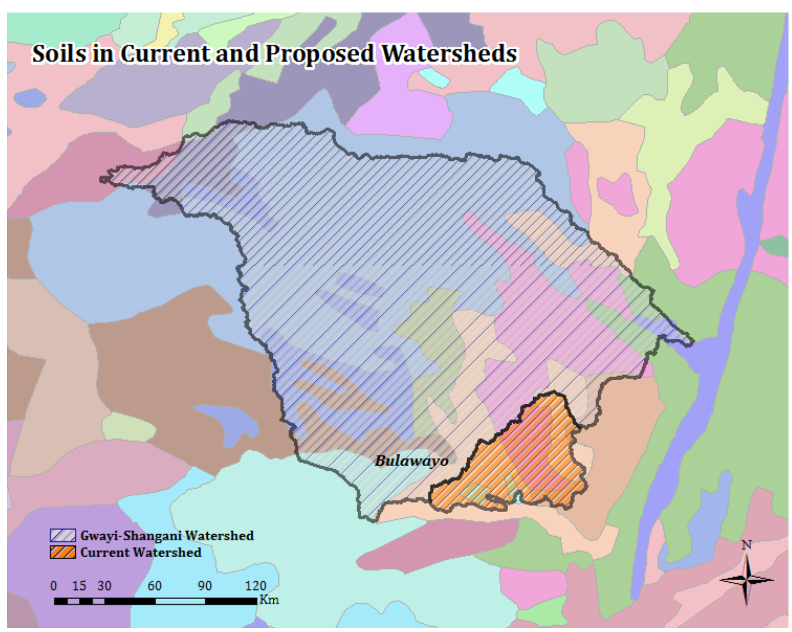


Figure 15



VII. Soil

The soil types between the two watersheds are fairly consistent. In fact, they share large contributions of Lc49-3a and Lf 82-1a (FAO classification, shown in Figure 15).

VIII. Dam Density

Particularly intersting in the case of Zimbabwe, is the density of surface water bodies (SWB, both dams and natural formations) that occur. Assuming that dams have some effect on the flow characteristics of given watershed, it may be reasonable to assert that a higher proportion of dams might lead to lower flow within the watershed altogether (Figures 16, 17, 18).

A shapefile of SWBs for Southern Africa was clipped to Zimbabwe. Spatial Joins were used to aggregate each type of SWB to distinct watersheds, according to the following classification:

Small	**<100 Acre-feet Capacity**
Medium	**>100, <10 000 Acre-feet Capacity**
Large	**>10 000 Acre-feet Capacity**

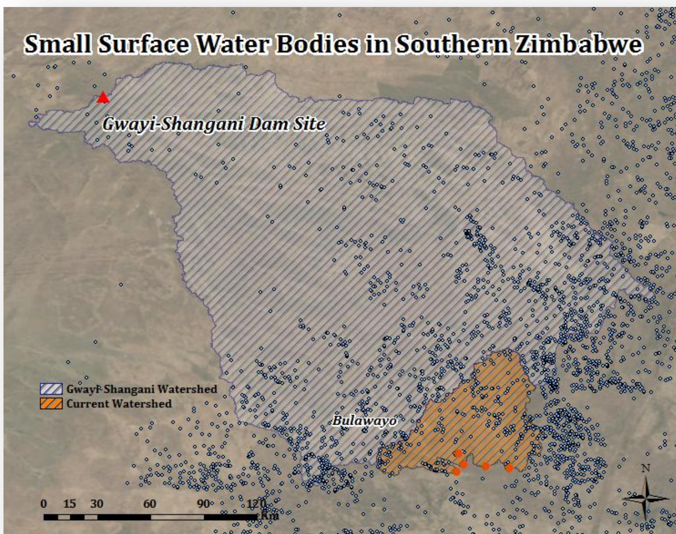


Figure 16

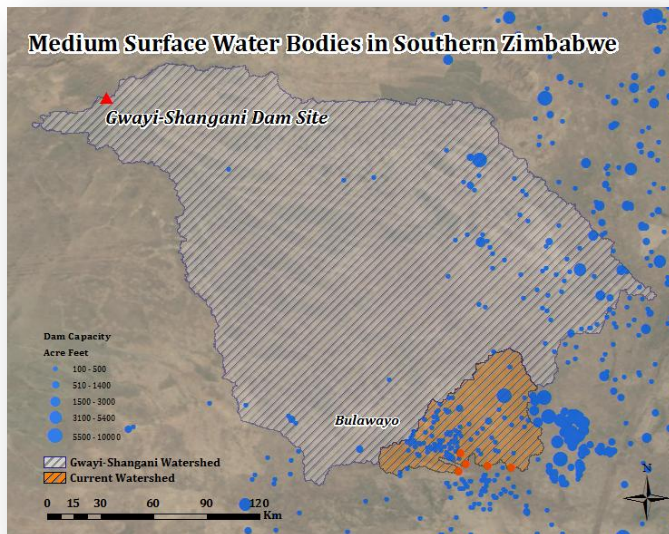


Figure 17

Below is a table detailing the relationship between the number and surface areas of small, medium, and large SWBs in each of the city's current watersheds, as well as the Proposed WS.

Number of SWBs	Current Watershed	Small	Medium	Large	Proposed Watershed	Small	Medium	Large
	U Ncema	21	58	0				
	L Ncema	2	8	0				
	Umzingwane	59	19	0				
	Inyakuni	1	10	0				
	Insiza	125	16	0				
	Total	**208**	**111**	**0**	**Total**	**1180**	**67**	**1**

Capactiy of SWBs	Current Watershed							
(Acre-feet)	U Ncema	354	8066	0				
	L Ncema	19	1063	0				
	Umzingwane	857	3064	0				
	Inyakuni	19	1179	0				
	Insiza	805	11708	0				
	Total	**2054**	**25080**	**0**	**Total**	**13903**	**37510**	**11698**

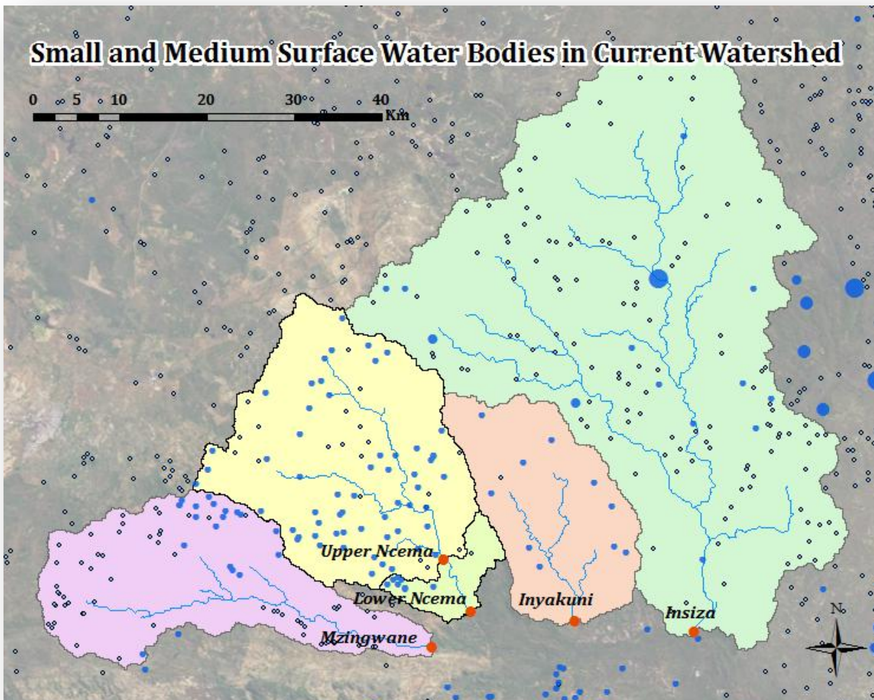


Figure 18

Taken together, therefore, the Current WS shows a total SWB density (number of SWBs divided by total area) of 319/3294 = **0.0968km-2**. The Proposed WS has a total SWB density of 1247/36810 = **0.0339km-2**. This is three times lower than the current watershed, a striking difference.

In terms of capacity of these water bodies, which might have an even more direct effect on the ability of a watershed to supply water, the Current WS has a total capacity density (capacity of SWBs summed over area, divided by area) of 27134acre-feet/3294km2 = **8.237 acre-feet/km2**. In contrast, the Proposed WS has a capacity density of just 50598/36810 = **1.375 acre-feet/km2**. This is much less than the Current WS, and could give some justification for planning a dam on the Gwayi-Shangani river.

Qualitatively, we also see that the western side of the Proposed WS has many fewer SWBs than the Current WS (Figures 16 and 17).

IX. Drainage Density

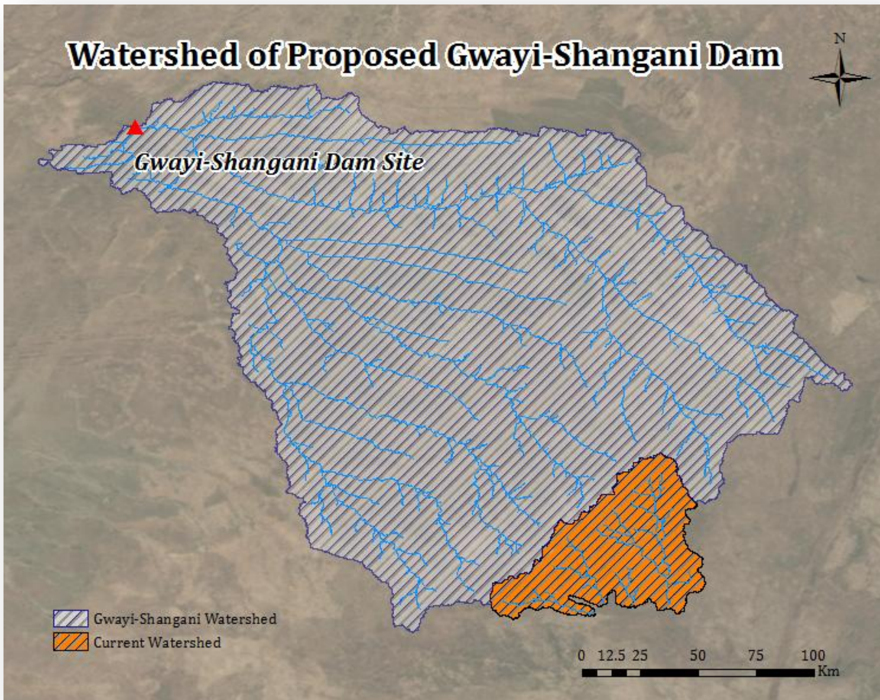


Figure 19

Finally, using the map algebra function and hydrology toolbox in ArcGIS, the delineated watersheds were processed to give the following statistics (Figures 19, 20):

Drainage Density	**Current Watershed**				**Proposed Watershed**		
	Name	**Length (km)**	**Area (km2)**	**Drainage Density**	**Length (km)**	**Area (km2)**	**Drainage Density**
	U Ncema	64	612	0.105			
	L Ncema	8	64	0.125			
	Umzingwane	64	465	0.138			
	Inyakuni	42	343	0.122			
	Insiza	252	1810	0.139			
	Total	**430**	**3294**	**0.131**	**4412**	**36810**	**0.120**

From this table we can see that the two different watersheds do not have a substantially different drainage density. However, the Proposed WS has the lowest drainage density of any, and care should be taken in planning for runoff.

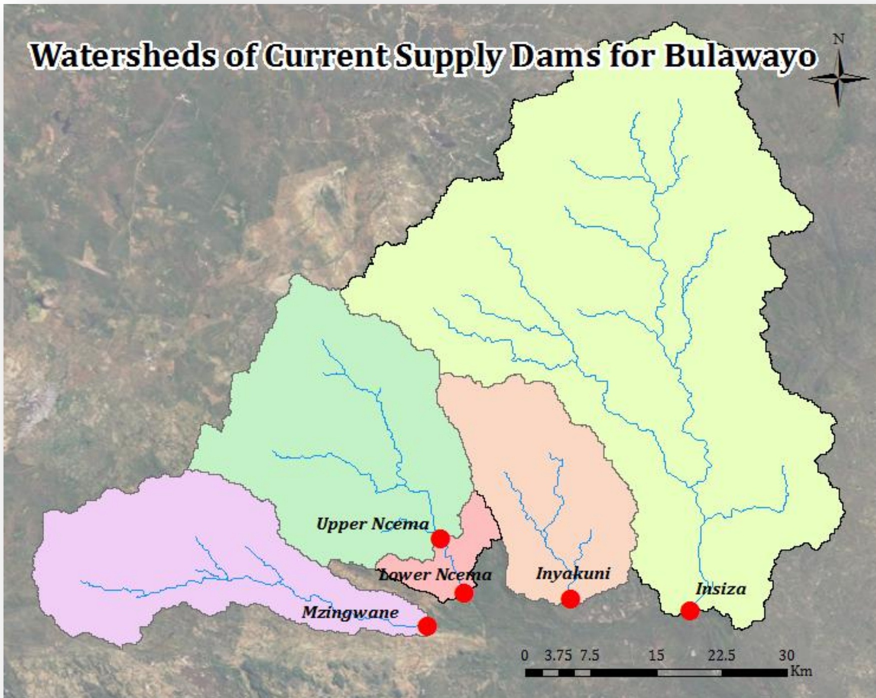


Figure 20

5. Summary of Findings

Several factors were used to evaluate the Current and Proposed watersheds. Though some are certainly more important than others (e.g. drainage density), consideration of each can add greater depth of knowledge to any plan to build a new dam in an uncertain environemnt such as that found in Southern Zimbabwe.

Taken together, it appears as if a new dam, such as the Gwayi-Shangani, is inevitable if Bulawayo is to properly address the city's water supply problem in the near future. Though many of the characteristics are similar between the Current and Proposed watersheds, there are important differences.

1. *Area (and Volume)* – The proposed watershed gives a much larger area of accumulation, giving a much larger potential water resource from the watershed.
2. *Number of SWBs* – The proposed watershed has a much lower dam density (by number and capacity). This will favor runoff reaching the potential dam site.

Given the factors above, the Gwayi-Shangani dam will potentially be able to supply the city of Bulawayo for many years to come. It should be noted, however, that economic considerations were not taken into account in this analysis, including the cost of the dam and associated pipeline construction and maintenance.

Bulawayo is suffering from a perfect storm of conditions: climatic, economic, geographic, etc. Yet if it hopes to improve its situation, it must learn from the past. Comparing the currently used watersheds for the city's dams to a proposed watershed for a new dam is one way of evaluating the potential viability of the new watershed. Like much of Africa, Bulawayo is urbanizing quickly, and therfore engineers and policymakers will need to continue to adapt. Supplying water to Africa in the future could mean fewer boreholes and more large-scale, modern urban systems.

6. Conclusion: The Role of GIS

This study has shown some of the uses of GIS in even the poorest regions of Africa (data and otherwise). Though Zimbabwe used to have a well-constructed hydrological monitoring system, current economic and political conditions have left it with limited resources. However, remotely-sensed data, freely available from different organizations, still allows for quite detailed analyses of even small watersheds.

Future work using GIS could incorporate GRDC data (even though dated), local data obtained from the City Council (if available), or one of several models applicable in this region

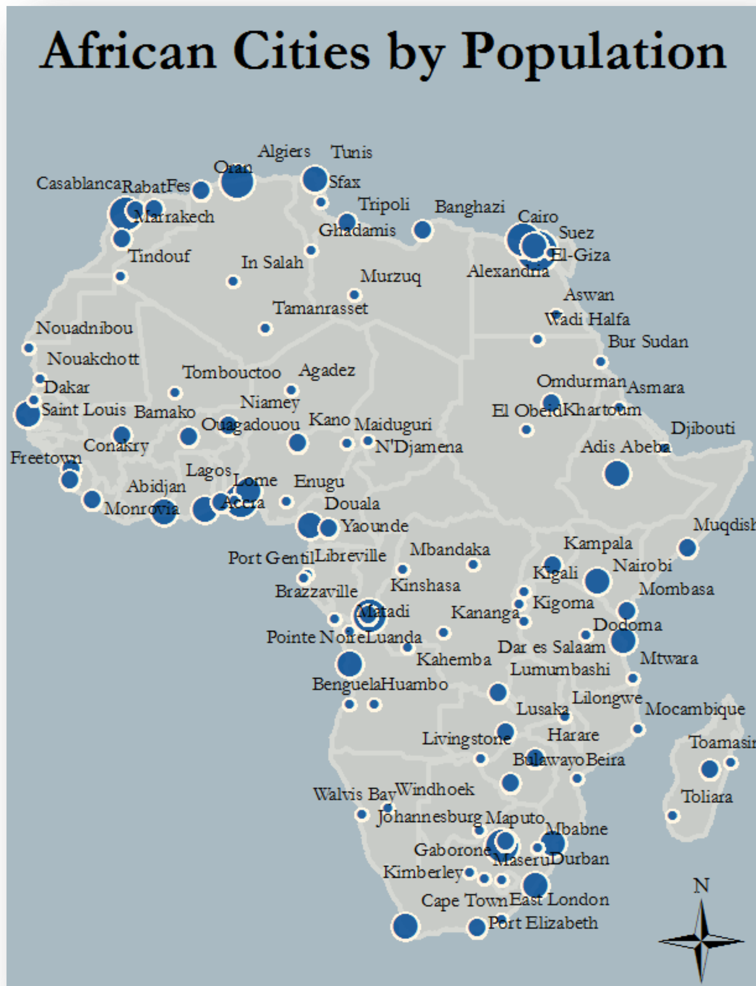


Figure 21

7. References

BBC News. (2012, September 24). *Synchronised toilet flush held in Zimbabwe's Bulawayo*. Retrieved from BBC News Online: http://www.bbc.co.uk/news/world-africa-19704766

Callow, R., & MacDonald, A. (2009). *What will climate change mean for groundwater supply in Africa.* London: Overseas Development Institute.

Karimakwenda, T. (2012, April 4). *Zimbabwe: Loan Scheme for Marginalized Areas Ignores Bulawayo*. Retrieved from allAfrica: http://allafrica.com/stories/201204051396.html

Makiwa, H. (2007, September 20). *Government withholds water to Bulawayo*. Retrieved from http://www.swradioafrica.com/news200907/byowater200907.htm

Mkandla, N., Van der Zaag, P., & Sibanda, P. (2005). Bulawayo water supplies: Sustainable alternatives for the next decade. *Physics and Chemistry of the Earth*, p. 938.

New Zimbabwe. (2012, July 12). *China funds $1,2bn Zambezi Water Project*. Retrieved from New Zimbabwe: http://www.newzimbabwe.com/news-8476-China+funds+$1,2bn+Zambezi+Water+Project/news.aspx

Nyabeze, W. R. (2005). Calibrating a distributed model to estimate runoff for ungauged catchments in Zimbabwe. *Physics and Chemistry of the Earth*, 625-633.

Onema, J.-M. K., Rockstrom, J., Mazvimavi, D., Love, D., Mul, M., van Rooyen, A., et al. (n.d.). *Influence of Human Activities on the Hydrology of the Insiza River, Limpopo Basin, Zimbabwe - Implications for Catchment Planning.* Lubumbashi.

The Economist. (2010, December 13). *Growth areas: The urbanization of Africa*. Retrieved from The Economist: http://www.economist.com/blogs/dailychart/2010/12/urbanisation_africa

The United Nations. (n.d.). *Millennium Development Goals*. Retrieved from United Nations: http://www.un.org/millenniumgoals/environ.shtml

UN Economic Commission for Africa. (n.d.). *Africa Water Vision 2025.* UNECA.