Empirical Modelling of the Water Supply Crisis in The Mpumalanga Province of South Africa

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Abstract

Large swaths of rural communities in South Africa are faced with water shortages. The Mpumalanga province is one of the most hard-hit areas in the country with very unskilled water administrators and old infrastructure exacerbating the problem. Lack of access to clean piped water affects local communities, surrounding agricultural farms and the few available industries in the province. The acid mine drainage at abandoned mine shafts also adds another dimension to the problem. In this research, the opportunities for poor communities to have access to potable water and also store enough water that will cater to the demand of water supply is investigated. The effective pumping systems strategic management are also addressed in this study to assist management to maintain the leaking and burst pipes. The delay in attending water related queries means more losses of water. An empirical investigation is conducted in the Mpumalanga province to identify the areas that have a water shortage and implement systems and strategies that will result in enough porTable water to the affected rural communities. The development of the empirical model and its testing with data obtained through questionnaires administered in the province forms the focus of this paper.

Keywords

Pumping System, Water, Communities, Empirical modelling, Mpumalanga, Pumping System, PorTable Water.

1. Introduction

In South Africa, water is a human right and the government has come up with several measures to ensure that all South African communities have access to this basic service at no cost. At the same time, South Africa is a country with a shortage of water and potable water in different areas especially rural areas. This study is focused on the rural areas in the Mpumalanga Province which is amongst the nine Province in South Africa. Mpumalanga lies in eastern side South Africa, bordering Swaziland, Kwazulu-Natal province, Free State province, Gauteng province, Limpopo province and Mozambique. It constitutes 6.5% of South Africa's land area, see Figure 1. The province has a large number of the townships, urban and rural areas and some surrounding industries and mines. The old mines also pollute the groundwater through the production of acid mine drainage (Mafanya et al, 2019a; Mafanya et al, 2019b; Mafanya, 2021). The rivers that run through Mpumalanga include Usutu, Crocodile, the Sabie-Sand and the Komati and the areas from which rainfall flows into these river channels are Olifants, Nkomazi, Usutu and Upper Vaal (Anon., 2017).

Figure 1: Mpumalanga in South African Country (Goverment, 2020).

The challenge of water supply in Mpumalanga Province is due to different factors, amongst them include the recent drought in South Africa that caused the flows of rivers to drop and subsequently drying of dams (Anon., 2019). The development of water infrastructure below standards affects the quality of the systems that are used to supply water to the communities. To address the situation of the water crisis in Mpumalanga, the department of Water and Sanitation has allocated funds to the municipalities for groundwater development under the drought relief intervention. The aim is to undergo a refurbishment of boreholes under drought relief involvement (Anon., 2019). Other studies have led to some devices, such as Atmospheric Water Generators (AWG), designed specifically for rural communities (Thisani et al, 2017; Thisani, 2018; Thisani et al, 2019).

In the process of government addressing the issue of the water crisis, it is still a challenge and a struggle with rural communities to have access to porTable water constantly. The existing infrastructures are not well maintained and managed to meet the demand of water to the consumers. They are constructed below standards, as a result, they don't last. In the process of water supply, the design, installation, operation and maintenance of the pumping systems and pumps is a challenge to the municipalities. The failure to choose correct pumps for the systems causes damage to the system and unplanned maintenance that is costly. Mpumalanga old mines also pollute the underground water, therefore, the province has to conserve its waters by building more dams, reservoirs and commission new water treatment plants (Mafanya, et al., 2019; Mafanya, et al., 2019; Mafanya, 2020; Anon., 2017). In other parts of the province, some areas access their water through illegal connections which overload the system and does not last as supposed. This study seeks to highlight the number of challenges that impact the delivery of water services in rural communities within the study area, specifically looking at the problems and issues that hinder the delivery of services as well as the impacts these have on the rural communities being serviced. It is desired to develop water systems and strategies to assist with solving the shortage of water due to drought, infrastructures and water quality (Anon., 2017)

2. Study Area

The study areas include Bushbuckridge and Mbombela municipalities. Rand Waterias supplying about 137 million litres per day of water to these municipalities. Bushbuckridge and Mbombela municipalities are located at the north-eastern part of Mpumalanga. Both municipalities are part of Ehlanzeni District of Mpumalanga, see Figure 2 (Mayher, et al., 2009; Anon., 2020). The population and the size of the selected areas are shown in Table 1.

Table 1: Population and Area of Bushbuckridge and Mbombela

Local Municipality	Population	Area km^2
Bushbuckridge	720 000	10250
Mbombela	588 794	7141
Total	1308794	17391

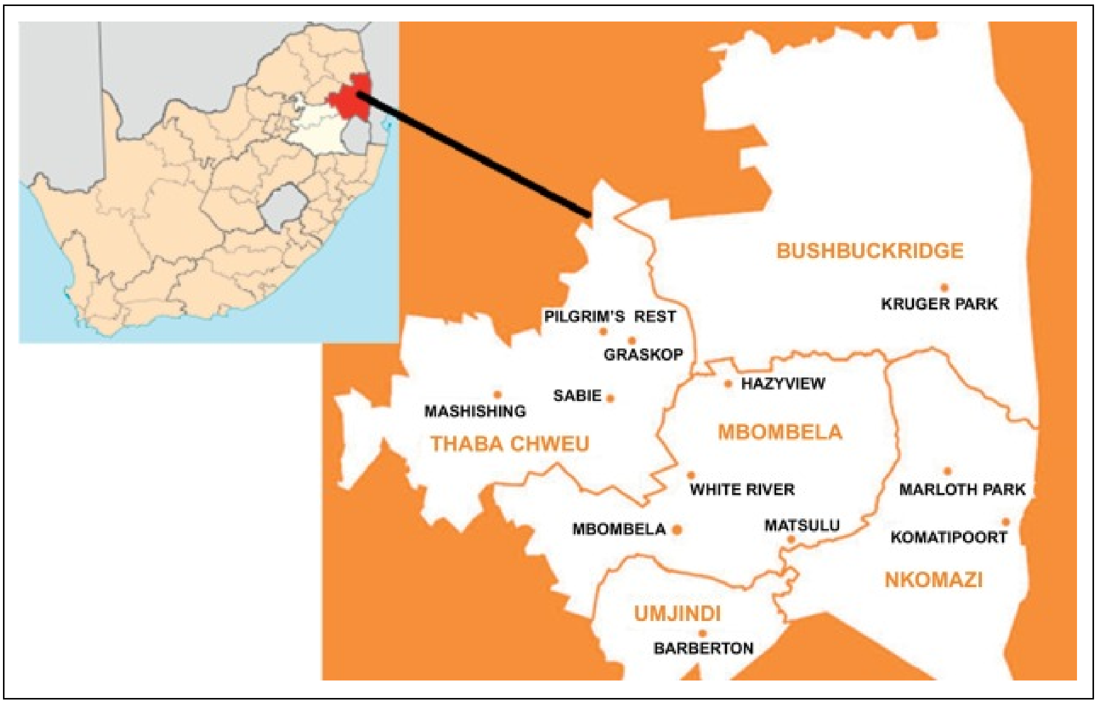

Figure 2: Map of Mpumalanga Province showing the location of Bushbuckridge and Mbombela Local Municipality (Mashile, et al., 2019)

3. Methodology

The study seeks to identify the communities in South Africa that are experiencing challenges in accessing water services with the intentions to investigate the challenge and implement systems and strategies that will speed up the process of delivering potable water to the communities. The study aim is to conduct a checklist to observe the existing infrastructure that has been installed by the municipality in selected areas. The focus on the infrastructure includes the boreholes, communal standpipes, existing treatment plants and reservoirs. Informal interviews and questionnaires were used to gather information on these issues.

4. Findings

The findings for the study areas are discussed in Table format. Table 2 outlines the overview of the water services of the study areas for this research. Amongst these areas, there are other subareas in the province that suffer the challenge of water shortage and unclean water. The physical observation of these areas shows that most of the villages survive with water from boreholes. The study shows that less percentage of the population receive salaries and as a result, the households cannot afford the cost of porTable water like people staying in formal urbanised areas. Table 2 also outlines the source of drinkable water in the study area.

Table 2: Overview of Water Services

Remote rural village	**Rural scattered village**	**Rural dense village**	**Formal urbanised towns**
Main source: Boreholes, Communal Standpipes, Rivers	Main source: Canal, Rivers, Communal taps.	Main source: Yard taps, Communal standpipes, Rivers	Main source: Household and yard taps, Communal standpipes.
The remote rural areas get their water from boreholes pumped into the reservoir. Also, the rivers are used as a source of water during the rainy season. Some areas suffer serious water scarcities and the section where refugees stay has no water services	The irrigation canal has been the major source of water. The river nearby is also a major source of water. There is an acute shortage of clean water. The small package plant established by the Lebowa Government provides purified water to the community, however, workshops revealed that the plant cannot provide water for the entire community. Very few people have access to water from this source (only two streets near the plant receive purified water). The rest of the community depend on raw canal water	Two boreholes in the village pump water into the Belfast reservoir. Many households have yard connections, most of which they have connected themselves. Households closer to the reservoir receive more water than households further from the reservoir. When the water quantity is low or nonexistent, community members access water via nearby rivers and wells.	Water is provided to the township via yard taps from the Hoxani Treatment Plant, which purifies water from the Sabie River. Outside the township, some areas have piped water with communal taps and some still access water from the Sabie, Benjani, and Xisimeleni Rivers

The primary source of drinking water for the communities is treated by municipal water. Other villages have community-level boreholes, storage tanks, and distribution tanks. The area of study gets the treatment water from Inyaka Water Treatment Plant. The plant gets raw water from Inyaka Dam which is an earthly dam with a height of 51m and width of 550m. The water then undergoes a standard treatment that includes pH adjustment, flocculation, settling, filtration, and chlorine disinfection (Matlakala, et al., 2019; Matlakala, et al., 2019). Water is then pumped to two elevated tanks and reservoir that supply several adjacent regions, including the study area. The challenge of the production industry is in the pumping systems and proper procedures should be implemented to operate it well (Matlakala, et al., 2019; Matlakala, et al., 2020; Randall & Whitesides, 2008). The challenges of water supply services in the study areas are discussed as follow;

4.1. Incapacity of operation and maintenance of the infrastructure

Shortage of water in these areas is due to lack of proper infrastructure to supply the bulk of water to communities. Most pipelines and reservoirs are old infrastructures hence produces undrinkable water. Poor maintenance of infrastructure also affects the supply of water because of water lost during the distribution period (Matlakala & Kallon, 2019). Poor maintenance and operation of the borehole affect the capacity of water needed to be supplied to the communities. Incapacity to operate the available infrastructure also contributes to the challenges of water supply services.

4.2. Illegal connections

The shortage of water to other communities is due to illegal connections. The communities are always growing, therefore, there is a need to upgrade the infrastructure to meet the demand as the population increases. New settlements connect illegally (Figure 3) on the mainline that supply the old communities, as a result, the capacity of water does not reach the designated destination. The illegal connections increase the load of the pumping system which will then result to water not reaching the designated destination. The pumping system is also at risk to be damaged due to the high amount of load that it was not designed for. The study shows that for the pumping system to last longer, the load in the pumping system must not exceed the normal load (Matlakala, et al., 2019; Matlakala & Kallon, 2019).

Figure 3: Illegal connection and leaking pipes

4.3. Mismanagement of resources

The budget constraints and limited resources also affect the shortage of water to the communities. The infrastructure needs to be upgraded always to increase the capacity of the water supply. Awarded tenders are not completed within the time frame, therefore, more budget is required to keep projects running, it will result in no funds for maintenance and continues operation. The water reticulation and treatment plants do not have chlorine to clean water before distributing to the consumers. The infrastructures do not last long because they are not built up to the standard, instead, cheaper material is used and no proper inspection and quality checks are usually done. Furthermore, incompetent people are involved in operation and maintenance hence there is mismanagement of resources. Sometimes resources are missing because of theft and vandalism and it cost the municipalities, see Figure 4.

Figure 4: Stealing of pump for borehole

5. The Design of the Pumping Systems

The issue of water shortages in the study areas is due to different aspects which were found during the investigation. The pumping system contributes to the municipalities challenges to supply communities with sufficient porTable water. The design of the pumping system helps with management of water delivery and avoiding of illegal connections. The pumping system design can always be revised based on the increasing population to accommodate every community member. In this study, the pumping system is designed to meet the demands of water supply to the area of study and also help the municipalities to do the proper installation, operations, maintenance and management of their infrastructure. To meet the requirement of the pumping system, the total dynamic head (TDH) is used. Dynamic head means there is a change of pressures, velocities, elevations and friction losses when the system and the pump are in operation (Matlakala, et al., 2020; Matlakala, et al., 2019). The Total Dynamic Head (TDH) is the combined total head of the following elements:

1. The pipe friction losses (H_f),
2. The static head (H_s),
3. The velocity head (H_v).

The sum of these three elements of the Total head leads to equation (1):

$$\text{Total Head} = H_s + H_f + H_v \tag{1}$$

The pumping system was designed based on the following system specification and assumptions;

The flow rate ranges from 0.05 to 0.4 m^3/s. The calculations are carried out at 0.05 m^3/s and the same procedure is used to calculate the pumping system to the flow rate of 0.4 m^3/s. The final results are summarised in Table 3. The material of the pipe is Commercial Steel pipe, therefore, pipe roughness is ε = 0.045mm, see Table 4.

Table 3: Pumping System Calculation Results of System 1 with a Pipe Length of 45m and Diameter of 0.3m

Flow Rate	**Diameter**	**Length**	**Area**	**Velocity**	**Reynolds Number**	**Friction Factor**	**Head of the System**
m^3/s	M	m	M2	m/s			m
0.05	0.3	45	0.07	0.71	118734.80	0.0182	32.92
0.1	0.3	45	0.07	1.41	237496.59	0.0164	32.05
0.15	0.3	45	0.07	2.12	356204.39	0.0156	31.33
0.2	0.3	45	0.07	2.83	474939.18	0.0151	30.77
0.25	0.3	45	0.07	3.54	593673.98	0.0148	30.35
0.3	0.3	45	0.07	4.24	712408.77	0.0145	30.10

Table 4: Absolute Roughness of Steel Pipe Material

Type of Pipe (Material)	**Absolute Roughness, ε (mm)**
Glass of plastic	Smooth
Drawn Tube	0.0015
Wrought Iron	0.046
Commercial Steel	0.046
Cast Iron	0.26
Riveted Steel	1.8

Pipe Diameter D = 0.3 m

Length of the pipe of the system = 45 m

The static head (H_s) = 30m

The friction head is the friction loss in the system that the pump must overcome. The friction occurs between the fluid and the internal surface of the pipe, valves, connections, and accessories in the suction and discharge of the pump. The equation of friction head of the pipe is represented in equation 2 (Bachus & Custodio, 2003; Yunus & Cengel, 2006);

$$H_f = \frac{f\,L\,v^2}{2gD} \tag{2}$$

Area of the pipe with the diameter of 0.3m is calculate using equation 3;

$$Area\ of\ the\ Pipe = \frac{\pi D^2}{4} \tag{3}$$

$$= \frac{\pi \times 0.3^2}{4} = 0.0707m^2$$

The velocity of the fluid inside the pipe is calculated using equation 4;

$$Velocity = \frac{Flow\ Rate}{Area} \tag{4}$$

$$= \frac{0.05}{0.0707} = 0.707m/s$$

The Reynold's Number (equation 5);

$$Reynold's\ Number = \frac{Velocity \times Diameter}{Kinematic\ Viscosity\ of\ Water} \tag{5}$$

$$Kinematic\ Viscosity\ of\ water\ = 1.787 \times 10^{-6}\, m^2/s^{-2}$$

$$Reynold's\ Number = \frac{0.707 \times 0.3}{1.787 \times 10^{-6}} = 118690.54$$

Friction factor;

Reynold's number is greater than 4000, therefore the flow is Turbulent.

5.1. For Turbulent Flow, equation 6 is used to calculate the Friction Factor;

$$f = \frac{0.25}{\left[log\left(\frac{\varepsilon}{3.7d} + \frac{5.74}{R_e{}^{0.9}}\right)\right]^2} \tag{6}$$

$$f = \frac{0.25}{\left[log\left(\frac{0.000045}{3.7\times0.3} + \frac{5.74}{(118690.54)^{0.9}}\right)\right]^2} = 0.018$$

The friction losses within the system at the flow rate of 0.05 m^3/s is found to be 0.0018

The friction Head is calculated from equation 7;

$$\mathrm{H_f} = \frac{\mathrm{f\,L\,v^2}}{\mathrm{2gD}} \tag{7}$$

$$\mathrm{H_f} = \frac{0.018 \times\ 45 \times\ (0.707)^2}{2 \times 9.81 \times 0.3} = 0.0687\ m$$

The velocity head (H_v) (equation 8) is given as;

$$\mathrm{H_v} = \frac{\mathrm{v^2}}{\mathrm{2g}} \tag{8}$$

$$H_v = \frac{0.707^2}{2 \times 9.81} = 0.0255m$$

Total head at 0.05 m^3/s is calculated from equation 9.

$$\text{Total Head} = H_s + H_f + H_v \quad (9)$$
$$= 30 + 0.0687 + 0.0255$$
$$= 30.09m$$

The calculations of the total head were carried out at different flow rates varying from 0.05 m^3/s to 0.4 m^3/s with the pipe diameter of 0.3 m and length of 45m. The final results are summarised in Table 3. It can be seen that the increase in the flow rate increases the total head of the pumping system 1.

The results of the pumping system design were summarised in Table 3. The same procedure was followed to calculate the pumping system 2 at the length of 60m of the pipe and diameter of 0.3m. The results for pumping system 1 and system 2 were plotted on the same graph in Figure 5 to illustrate how the system curve will change if increasing the pipe length from 45 to 60 m and further. Figure 5 shows that the pumping capacity can be achieved by adjusting the length of the pumping system at a constant diameter of the system. Increasing the length of the pipe in a pumping system the head increases, see Figure 5.

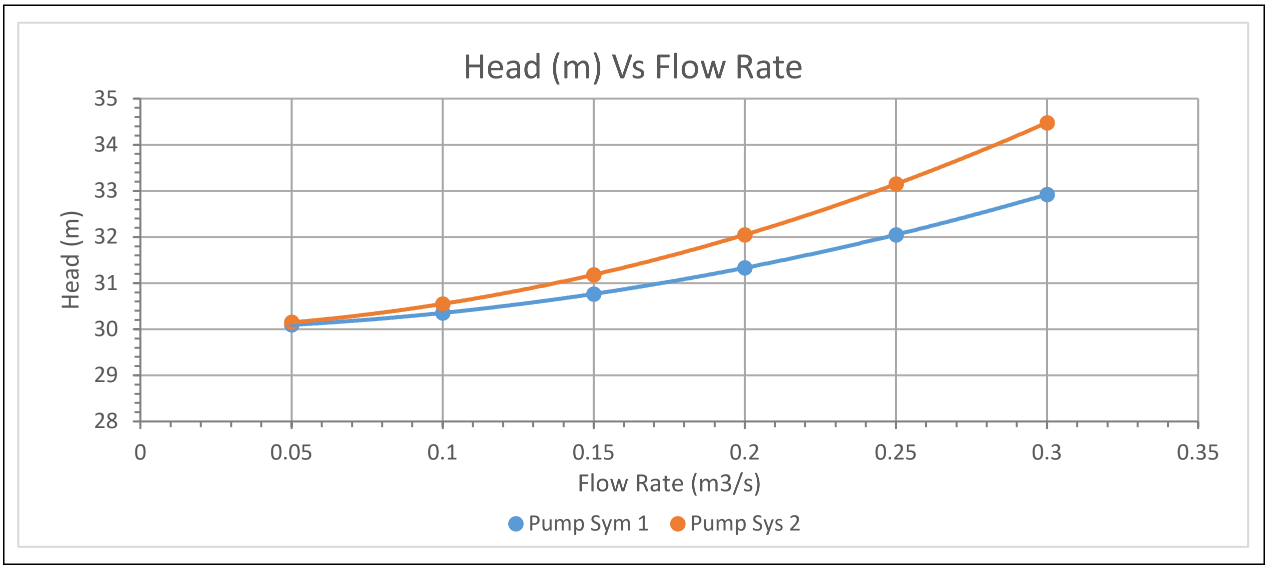

Figure 5: Pump system curve 1 and 2

6. Recommendation

It is recommended that the municipalities hire competent engineers and operators to manage the existing infrastructure. The management of the infrastructure includes the plans for operations and maintenance to ensure that the communities get sufficient drinkable water. The municipalities should invest in training and development activities to the communities and teach them about the importance of saving water and working together to fight against vandalism. The existing infrastructures need to be maintained to avoid unplanned maintenance that comes at high cost to the municipalities. The pumping system needs to be designed in a way that it can accommodate more than the existing population so that the increase of settlement does not affect other areas with water shortages. It is important to also have spare parts in case there is damage to the pumping system, maintenance can be done without disturbing to the supply of water on a daily base. The water that is pumped from the boreholes to the reservoir and storage tanks need to be tested to meet the quality standard of drinkable water.

7. Conclusion

The study concluded that a lot of rural communities in the study areas are facing challenges with water services which range from lack of capacity, skilled people, illegal connections and droughts which resulted into fountains being dry and the percentage of dams decreasing. The challenges affect the delivery of water services to the communities and need to be addressed with the purpose of improving the water delivery. The health of people is also at risk because of consuming untreated water. The abstracted water needs to be treated to meet the portable quality standard for drinkable water before it is distributed to the consumers. The infrastructures must be maintained frequently so that the quality of the water does not get affected through the supplying process. To manage the increment of populations, the design of pumping systems is critical to help with managing the bulk of water supply and with eliminating the problem of illegal connections. Figure 5 shows that the water supply can be increased by increasing the length of the system. The total head increases and the flow rate must be kept as small as possible to avoid the damage of pumps in the system. The vandalism and mismanagement of water can be solved by providing training of water-wise and management of community facilities. Skilled people should be employed in the municipalities to help with the management of the existing infrastructure and innovations that will assist with meeting the water demand of the communities.

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