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Procedia CIRP 119 (2023) 487–494

www.elsevier.com/locate/procedia

33rd CIRP Design Conference

Designing an Alternate Water Security Strategy for Rural Communities in South Africa – Case Study of Limpopo and Mpumalanga Provinces

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Abstract

Short of affordable and clean potable water poses high risk to health of human beings globally. Water scarcity is a challenge that affects all countries across the globe and this is more prominently felt in rural communities of poorer countries. In recent years, South Africa has faced severe droughts limiting portable water supply to rural areas of the country. Developing an alternate water security strategy for rural communities in South Africa can assist local government to manage water systems successfully. This paper illustrates the process of building a water supply strategy using the case of water management in Limpopo and Mpumalanga provinces of South Africa. These provinces experience a high challenge of water supply and access due to lack of water services, and challenge of building stakeholder support for resource management strategies. A number of rural communities were visited, water samples collected from boreholes, rivers, dams and taps around the two provinces. From chemical and other test, we established the quantity and quality of water sources around the two provinces. System dynamics and system analysis approach are used in this paper to model the existing water resource management and map out its frailties and limitations. A model to connect a system of boreholes and nearby water sources was then developed. The results, it is observed that the reliability and improvement of water system for rural areas was achieved through these approaches. The results show enhanced abstraction of water from sources within the communities that can secure water in these rural communities.

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Peer review under the responsibility of the scientific committee of the 33rd CIRP Design Conference

Keywords: Potable Water; Mpumalanga Province; Limpopo Province; Water Security; System Dynamics; System Analysis.

1. Introduction

Water is a basic need to all South Africans. Everyone has a right to access of potable water daily. Policies are established to support the plans and management strategies to ensure that residence have access to potable water supply in the country [1]. Every year there is a budget allocated to water services and improvement of water infrastructures. The country is experiencing high level of water shortage even though measures are put in place to ensure access to potable water [2]. Accessible water in most areas is contaminated and as a result, it poses a risk to health of consumers. Shortage of water affects people's health, led to hunger and poverty [3, 4, 5]. The quality of water is often compromised from the source to consumers. Effective management strategies should be prioritized to ensure that water quality is supplied [4]. This study is focused on the rural areas in the Limpopo and Mpumalanga province of South Africa. The Limpopo Province lies in Northeast of South Africa bordering Mozambique, Mpumalanga Province, Gauteng Province, Northwest Province, Botswana and Zimbabwe. Mpumalanga lies in eastern side South Africa, bordering Swaziland, Kwazulu-Natal province, Free State

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10.1016/j.procir.2023.03.110

province, Gauteng province, Limpopo province and Mozambique. Limpopo and Mpumalanga provinces cover 10.3% and 6.5% of South Africa's land area respectively. The provinces have many rural areas, townships, a few urban areas and surrounding industries and mines. Limpopo and Mpumalanga provinces are among the regions that experience higher levels of water shortages. The existing population within Limpopo and Mpumalanga provinces including urban and rural areas was recorded in 2022 to be 6 102 000 and 4 776 939 respectively [6, 7]. It was noted that the population has been increasing over the years. As the population in provinces increases yearly, the water scarcity issue also increases since there is lack of water supply in provinces and its surrounding areas because of the lack of facilities to meet demand. Lack of water supply is mainly due to the lack of proper water supply systems, increase of population and challenge of building stakeholder support for resource management strategies. Lack of potable water in the provinces has caused individuals to come up with their own solutions by joining unapproved pipeline links from the main link to their households [8, 9]. Rural communities make use of self-supply strategies to access water for multiple purposes such as domestic use, irrigation and livestock. Rural communities make use of boreholes or groundwater to access water for multiple purposes. In these provinces, it was observed that self-supply improved access to water faster and is more cost-effective and sustainable than public services do [3]. Old mines also pollute groundwater [6, 7, 8]. The current hot temperatures in the country have plunged Limpopo Province into a water stressed region as levels of dams and rivers has dropped to low percentages due to lack of rain. The infrastructures are not well maintained and managed to meet demand of water by the communities, as a result, they don't last [9]. Rural areas in the provinces rely on the pit latrines as their primary means of sanitation and this causes human and ecological health impacts associated with microbiological and chemical contamination of groundwater tables [10].

Other communities buy untreated water from household with boreholes. Provision of alternative water sources such as Atmospheric Water Generators *(AWG0 have been investigated for rural areas in South Africa, although these are not in wide use [15, 16, 17]. Developing an alternate water security strategy for rural communities in these provinces can assist local government manage water systems successfully. This paper illustrates the process of building a water supply strategy using the case of water management in Limpopo and Mpumalanga provinces of South Africa. A few rural communities were visited, water samples collected from boreholes, rivers, dams and taps around the two provinces. From chemical and other test, we established the quantity and quality of water sources around the two provinces. System dynamics and system analysis approaches are used in this paper to model the existing water resource management and map out its frailties and limitations. A model to connect a system of boreholes and nearby water sources is then developed and tested in GO Bowtie software.

2. Methods and Materials

In this study, data was collected between January 2021 and December 2021 in both provinces. Permission to conduct the research was obtained from Chiefs and municipalities of the area. Data was collected through interviews, observations, and physical measurements. The main reason was to find out about the challenges associated with shortage of water using survey and followed-up with interviews with the community representatives. The data obtained through questionnaires was validated by developing an empirical model to improve the existing model. For the exploration of this study, desktop study was done, interviews and documentation analysis are utilized. Secondary data was gathered through the provincial website, documents, and newspapers. A consecutive investigative mixed method was used, see Figure 1.

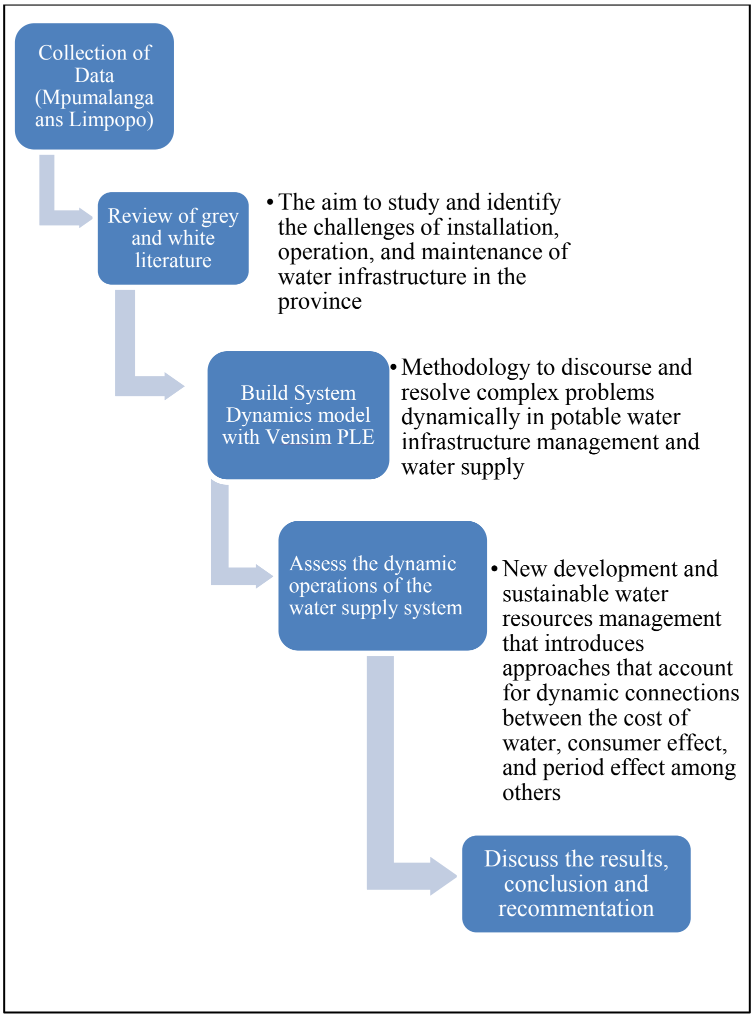

Fig. 1. Consecutive Investigative Mixed Method.

The integration and management of water infrastructures of water systems and municipalities in charge of the systems, requires integrative approach to provide an understanding of water challenges and its context.

2.1. System Dynamics Model

Municipalities find it difficult to manage the water systems due to complexity and interdependence of water resources. A system dynamics approach is used to provide a deeper understanding of water problem [16]. The main objective of the research is to develop a water supply chain systems dynamic model to determine the nature and causes of water crisis associated with water supply systems in the rural communities of Limpopo and Mpumalanga province. Vensim PLE 8.0.9 software is used to develop system dynamics model. Dynamic simulation helps to observe the behavior of a modelled system and response to interventions over time. The basic elements of systems dynamics model are described in detail in Table 1 [12]. It deals with the interpretation of the dynamic nature of systems in which information and material feedbacks are present.

Table 1. The basic elements of systems dynamics model

Symbols	Names	Definitions
	Arrow	Shows a direction between two variables
Auxiliary Variable	Auxiliary Variable	Supporting variables that are constant
	Rate	Rate, also called flow variable, the cloud mark at the end or beginning of the rate represents a sink or a source.
Level	Stock/ Level	It represents accumulation

The System Dynamics Methodology developed is based on systems theory. Causal loop diagram in Figure 2 shows the negative and positive interactions between components that contribute to the supply of potable water. The stock-flow diagram in Figure 3 is created from 2021 to 2051, 30 years of projection. It also illustrates the interactions between different factors that contribute to the shortage and availability of water supply.

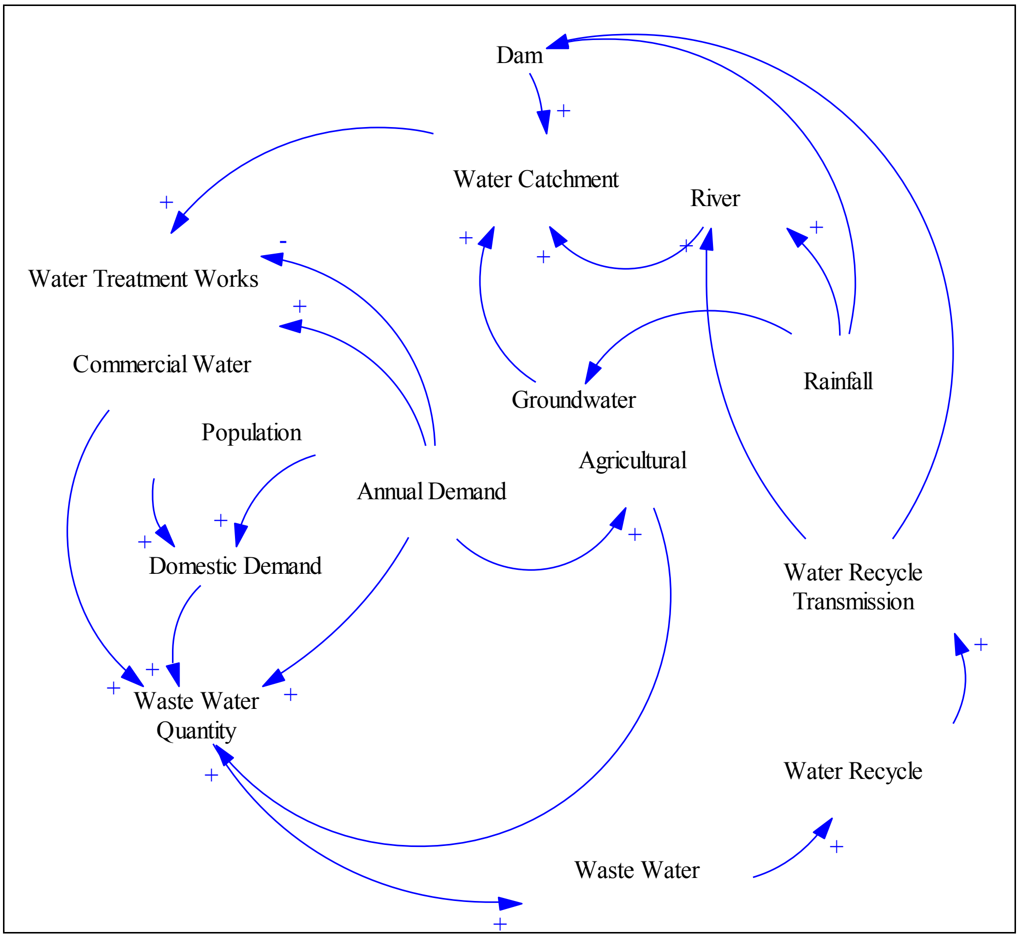

Figure 2. Causal loop diagram shows the negative and positive interaction between components that contribute to the supply of potable water.

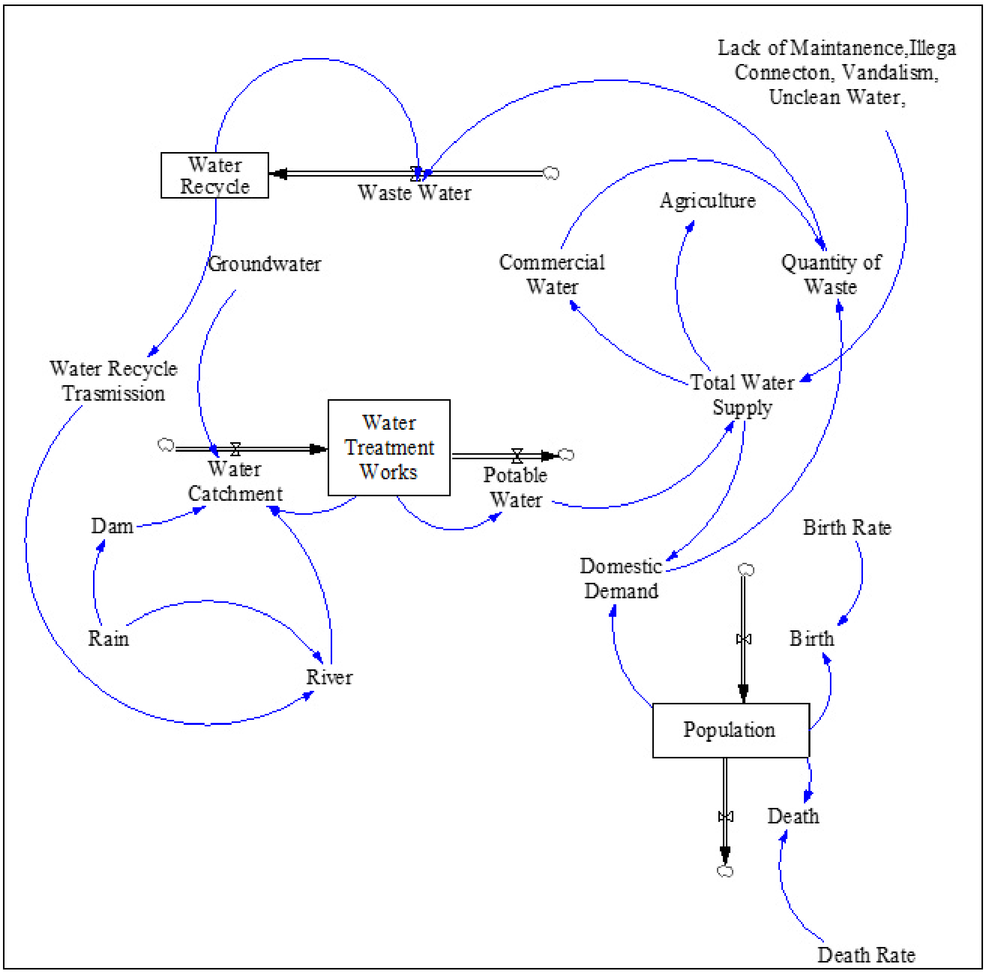

Fig 3. Stock-flow diagram created from 2021 to 2041, 20 years of successful projection.

3. Results and Discussions

The results and analysis of this paper are presented in three main sections. Section 3.1 focuses on the status of water supply in different areas around Limpopo and Mpumalanga provinces. This is followed by section 3.2 which presents the discussion of the models and analysis of the results. Section 3.3 focuses on the development of the alternative water supply plant.

3.1. Status of Water Supply in Limpopo and Mpumalanga Provinces

During visits to Limpopo and Mpumalanga provinces, it was found that the municipalities have independent sources of water, and they supply their own communities independently. From interviews, observations, and the tour around the provinces, it was found that the provinces experiences high levels of water shortages due to a range of factors. It was also found that:

- Water infrastructures are old and not maintained. As a result, the quality of water is affected.
- Rural communities make use of boreholes or groundwater as their main access of water for multiple purposes like domestic use, irrigation, and livestock.
- In these provinces, it was observed that self-supply in rural areas improved access to water faster and is more cost-effective and sustainable than public services do.
- Rural communities do not have water and sanitation, pit latrines are used as their primary means of sanitation which contaminates the groundwater. Other communities buy untreated water from the household with boreholes.
- Mining industries occupy a large amount of area in both provinces. Old mines contaminate groundwater.
- Areas with water infrastructure, new residences temper with water pipes which causes leaks and overloading the system.
- No continues maintenance of water systems, as a result, the systems do not last longer.
- In the formal urbanized towns, Water is provided to the townships via yard taps from the Treatment Plants, which purifies water from Rivers and Dams in the provinces. Outside townships, some areas have piped water with communal taps.

3.2. System Dynamics Model Analysis

In Figures 4-6, the blue trend represents the behavior of a water system in a condition where there is consistency in managing water systems. The red trend represents the behavior of water systems with no consistency in maintenance and upgrade of the water systems to meet demand. Illegal connections, vandalisms and unclean water have impact on the behavior of the water system.

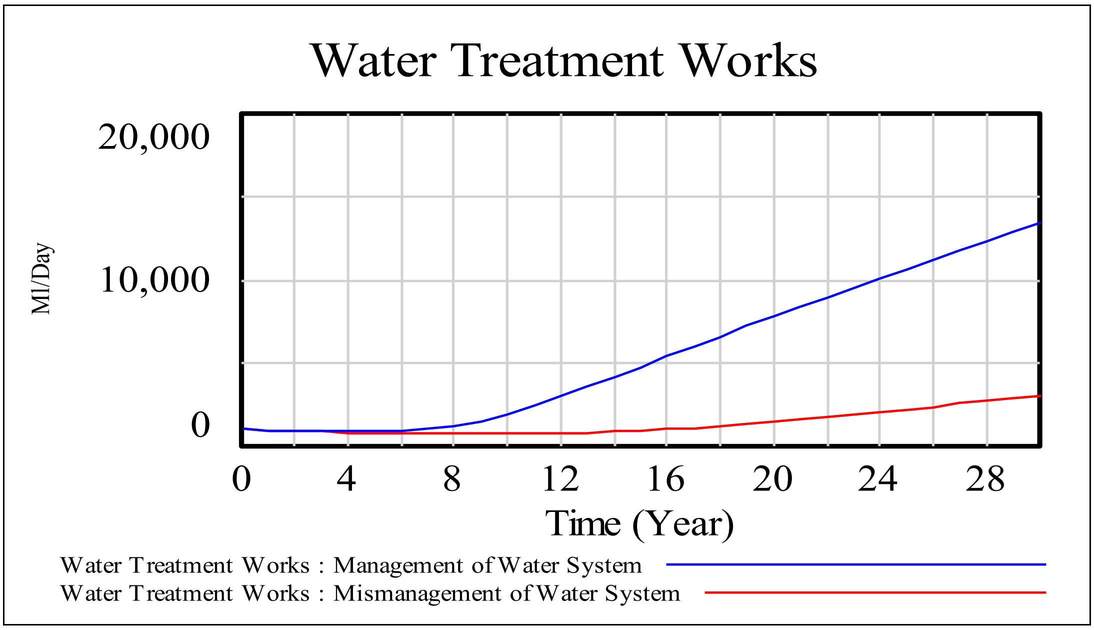

Fig 4. Simulation Results of Total Water Supply.

It can be observed in Figure 4 that mismanagement (Red trend) of water systems reduces the total amount of treated water which will concurrently affect the total water supply as is shown in Figure 5. The complexity of water systems makes it difficult for the municipalities to manage efficiently.

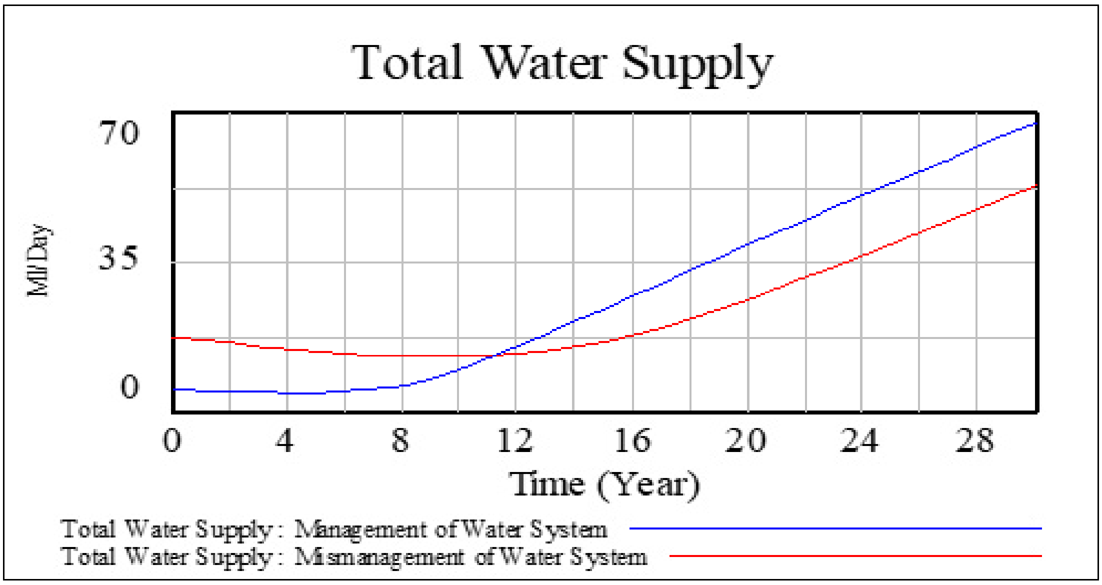

Fig 5. Simulation Results of Water Treatment Works.

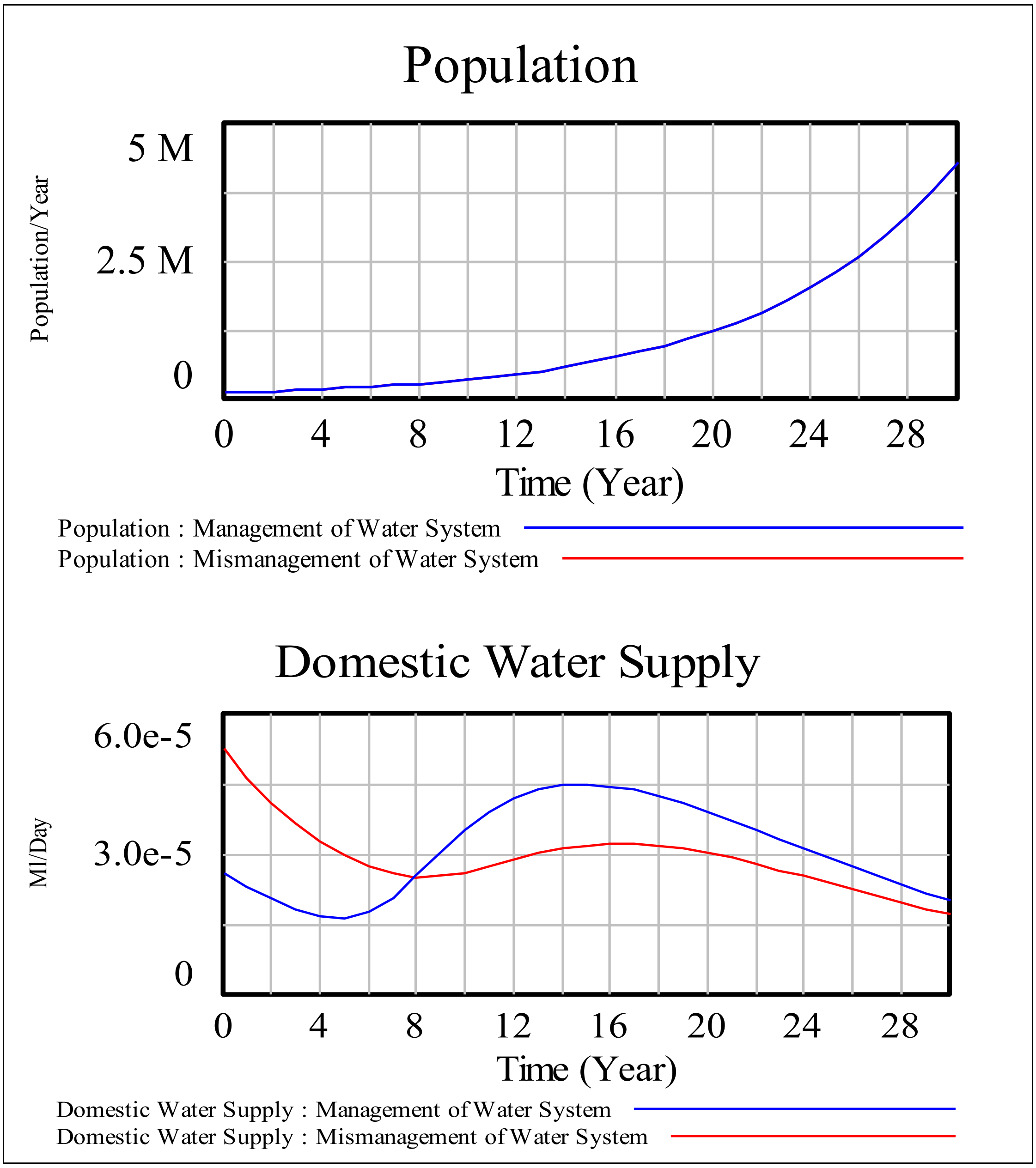

Fig 6. Simulation Results Comparing the Rate of Population and Domestic Water Supply

The relationship between the population and domestic water supply is illustrated in Figure 6. It can be observed that an increase of population will eventually reduce domestic water supply. Domestic water supply reduces even more when the water systems are not managed (red trend) as compared to when management strategies are being implemented (blue trend). The Figures 4 and 5 show that system dynamics tools are useful in helping local municipalities in Mpumalanga and Limpopo provinces to accurately estimate the amount of water required based on strategic management of water systems. The difference between the trends is a lot which indicates that mismanagement of water systems has major impact on the amount of water supply. It is with this model that the municipalities can also improve their management systems to ensure that there are no water supply disruptions.

3.3. Development of the Alternative Water Supply Plant

Based on the observation, desktop study of the water supply systems of the provinces and system dynamics model, alternative water supply plant is developed. Rural areas utilize boreholes or ground as their source of water. A new water supply plant suitable to supply water in rural area is show in Figure 7. The plant is working as following.

- It receives raw water from the borehole or groundwater and domestic used water.
- Raw water is stores in a raw water tank for water treatment residue process to take place before filtrations so that unwanted can be removed. It becomes cheaper to filter water after water treatment residua took place.
- The water is transported to filter to remove unwanted particles and minerals.

- After filtration process, potable water is store in a clear well before is distributed to the consumers.

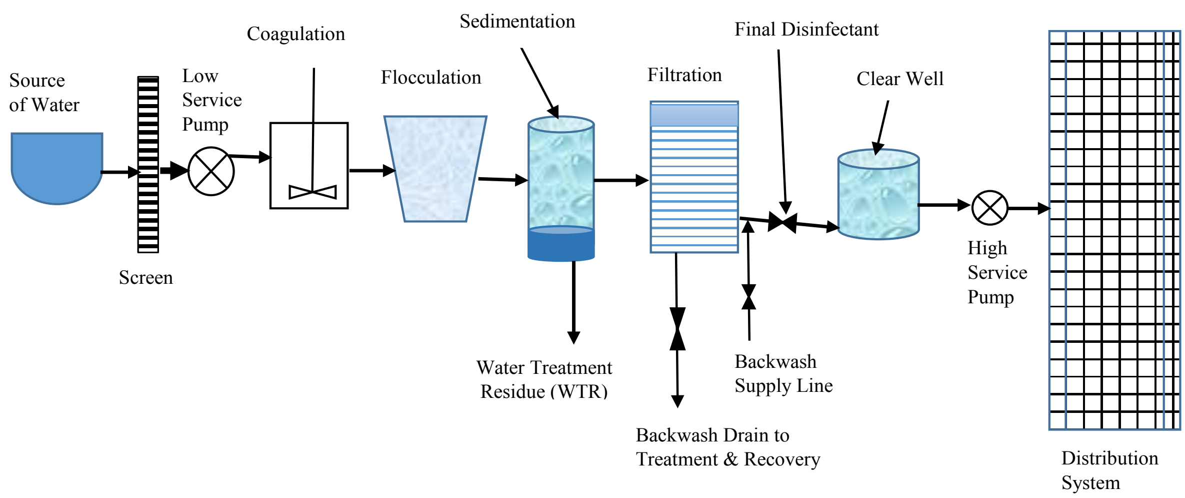

Fig 7. Schematic Diagram of Water Supply Plant

4. Conclusion

In this paper, alternative water supply plant and system dynamics model were presented to forecast the long-term effects of managing of potable water systems in Limpopo and Mpumalanga provinces of South Africa. The results show that mismanagement of resource to maintain potable water infrastructure will result into reduction of potable water availability. Continues maintenance is critical in a water supply environment so that potable water is available. This requires many employees to do maintenance frequently which is costly. System dynamics is the most usable approach to easily manage and strategically maintain water infrastructure. It also helps to understand cause and effect relationships of different factors that contributes to availability of potable water. System dynamics model is created to estimate dynamic performance of water supply systems of Limpopo and Mpumalanga provinces. System dynamics model is introduced because Limpopo and Mpumalanga provinces water supply services require a sustainable water resources management approaches that accounts for dynamic connections and all factors that contribute to water quality, water supply and water management.

Acknowledgements

We would like to acknowledge the University of Johannesburg for resources and support to write this paper.

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