Vol. 13(2), pp. 135-153, April-June, 2021
DOI: 10.5897/IJWREE2021.0996
Article Number: B5664E666693
ISSN: 2141-6613

http://www.academicjournals.org/IJWREE

International Journal of Water Resources and Environmental Engineering

Full Length Research Paper

Water supply interruptions in Umzinto Water System: Ugu District, South Africa

Lorraine Thulisile Mwelase[1]* and Rimuka (Bloodless) Dzwairo[2]

[1]Department of Civil Engineering and Geomatics, Durban University of Technology, P. O. Box 1334, Durban, 4000, South Africa.
[2]Durban University of Technology, Civil Engineering Midlands, P. O. Box 101112, Imbali, 3209, South Africa.

Received 03 February, 2021; Accepted 14 April, 2021

The Constitution of the Republic of South Africa states that all citizens have a right to access adequate food and water. However, water services provision has remained one of the biggest challenges faced by most municipalities. The Umzinto water supply system under the auspices of the Ugu District Municipality (Ugu DM) was selected as the study area to evaluate the water supply interruption frequency. Data range for the study was from 01 November 2015 to 31 December 2019. The highest number of interruptions was experienced in Umzinto town, Uswani, Amangamazi and Amandawe areas. The infrastructure was outdated and needed to be replaced as a matter of urgency. Other interventions that needed to be implemented were recommended included consumer awareness programme, consumer enumeration and connection, billing and collection and routine maintenance. The lack of planned maintenance for some of the infrastructure had led to it deteriorating to a level where it had become too expensive to maintain and repair, but the only sustainable solution was replacement.

Key words: Water supply, access, water services provision, interruptions, aged infrastructure, operations and maintenance, sustainable, municipalities, spatial and temporal trends, Umzinto Water Supply System.

INTRODUCTION

The water supply interruptions as reported by the consumers and recorded in the fault management system during the study period were evaluated and plotted on the GIS. This exercise comprised all the system failures, frequency of the failures, causes of the failures, how they were resolved and the short-term and long-term solutions. The information on all the system failures was obtained from the fault management system. An analysis of the cause of each failure and how it was resolved was obtained from the job cards. Depending on the cause of the failure, short-term and the long-term solutions were developed. The specific objective of this study was to evaluate the interruption frequency analysis for the Umzinto Water Supply System.

Access to potable water is a crucial issue globally; however, the goal to provide water for all has not been

*Corresponding author. E-mail: thuli.mwelase19@gmail.com. Tel: +27824469462.

completely realized so far (Grady et al., 2014; Lester and Rhiney, 2018). Grady et al. (2014) noted that there were restrictions in both developed and developing countries, which might not be the same, but could be grouped according to social, technical and political criteria. These groupings of limitations were experienced in many developing countries resulting in challenges in ensuring that people had access to uninterrupted supply of safe water (Nganyanyuka et al., 2014). Developing countries faced barriers in the design, implementation and the Operation and Maintenance (O&M) phases, while developed countries faced issues related to ageing infrastructure and water availability (Parlikad and Jafari, 2016).

The main aim of the O&M exercise is to ensure efficiency, effectiveness and sustainability of water supply system. Ducrot (2017) agreed with these findings and noted that consumers in developing countries had started managing the water supply on their own. This study further identified sustainability of water supply infrastructure as the key challenge experienced by rural water supplies in developing countries. A progress report provided by Statistics South Africa (2015) for the Millennium Development Goal (MDG) on water supply indicated that 89.1% of the people had access to better water services in 2005. Whilst it was appreciated that considerable effort had been made in improving access and reducing backlogs, the maintenance of existing infrastructure still fell behind in terms of priority (Rodriguez et al., 2012; Yazdandoost and Izadi, 2018).

This lack of maintenance was of great concern because there were positive returns in investing in infrastructure maintenance, such as an increased lifespan of infrastructure, water use efficiency and customer satisfaction (Mwanza and Mbohwa, 2016). For any country to get these returns and achieve its economic growth target and a reduction in poverty, it was important for water infrastructure to receive adequate maintenance for sustainability (Furlong et al., 2017; Pryke and Allen, 2018). On the other hand, although new systems might need to be built to cater for a growing population and a change in income patterns, the deteriorating infrastructure would require refurbishment to maintain levels of service (Wang et al., 2017).

Successful government institutions allocated sufficient budgetary funding to keep infrastructure preventatively maintained (CSIR, 2007; Kuo and Cheng, 2018). These institutions had also retained skilled staff and trained new personnel. However, Van Zyl (2014) and Yazdandoost and Izadi (2018) noted with concern that municipalities generally had not managed their assets effectively due to growing demands in the quantity, capacity and quality of infrastructure services and the deterioration of existing infrastructure. Note (2017) reported that consumers were often provided with limited resources because water services could deteriorate gradually over time without them noticing. Water infrastructure, specifically, could operate without adequate maintenance but once it reached its life expectancy period, huge amounts of money were required for replacement (Note, 2017).

Within the study area, the Ugu DM experienced numerous water supply interruptions over time for various reasons. Ageing infrastructure and inadequate budget to replace this infrastructure were identified by the municipality as the two main reasons for these supply interruptions (Ugu District Municipality, 2019). Therefore, there was an urgent need for a framework that would assist the municipalities with the O&M of the infrastructure to avoid such incidences. Each municipality operated and maintained its infrastructure according to its O&M plan and maintenance policy but others did not identify the need to prioritize O&M until the infrastructure collapsed.

Magombo (2017) recommended a maintenance, renewal and replacement of infrastructure programme to ensure minimal water losses. Water had been referred to as being among the most mismanaged resources and posed a huge challenge for environmental and agricultural administrators as well as water managers (Molobela and Sinha, 2011; Smetanová et al., 2018). According to Meissner et al. (2018), South Africa was currently faced with water supply challenges with huge backlogs in water service delivery. Also, the existing infrastructure was ageing and needed replacement whilst there was inadequate budget to address those challenges. Koop and van Leeuwen (2015) concurred that the renewal of ageing water supply infrastructure was a global problem impeded by escalating costs. Substantial funds needed to be invested in the continuous rehabilitation of the water supply system.

Nafziger and Koo (2015) agreed that the refurbishment costs and the capital funding required for the improvement and development of infrastructure was very high, and for these amounts to be met, service fees and rates needed to be increased. In order to achieve this, decision-making in water infrastructure had to be characterized by a rational, cost/benefit-driven approach (de Graaf and van der Brugge, 2010; Dong et al., 2018). This was supported by Opresnik and Taisch (2015) who stated that infrastructure investment was one of the important practices that had to be adopted by government and that projects with uncertainties should be rejected. According to Hui et al. (2018), the planning for infrastructure should be motivated by financial benefits and costs as well.

Table 1 indicates the countries, which have complied with the MDG goal for potable water and sanitation. Out of the 192 countries that were surveyed for the potable water target, only 60% had reached the MDG target while 16% were on target to reach the goal. Some 2% of the countries had made insufficient progress and 20% were not on target to achieve the MDG goal. In terms of the

Table 1. Number of countries in comparison in respect of the MDG goal for potable water and sanitation

Variable	Potable water	Sanitation	Potable water and sanitation
Reached target	116	77	56
On target to reach the goal	31	29	30
Progress insufficient	5	10	-
Not on target to achieve the goal	40	69	20

Source: WHO/UNICEF (2014).

sanitation targets, 42% of the surveyed countries had reached the MDG target and 16% were on target to reach the MDG goal. Some 5% of the countries had insufficient sanitation targets and 37% were not on target to reach the sanitation goal. While the SDGs took over from the MDGs, the MDGs are still important because they reflect the commitment shown by leaders of different countries to fight hunger, poverty, illiteracy, disease, environmental degradation and discrimination against women.

There was a need for substantial investment to refurbish the existing infrastructure in order for them to conform to strict health and environmental guidelines and to sustain service quality (Hukka and Katko, 2015; Bostick et al., 2018). This meant that in order to ensure operational efficiency, infrastructure needed to be built, maintained and upgraded to meet the demands at any given time. The other options that were available to ensure water security were human capacity building, public participation, good governance, government awareness and promotion of water conservation and water re-use (Rodda et al., 2016).

However, the aforementioned options were not without challenges as the prevailing infrastructure operations lacked management, particularly the growing demand which was not managed, rendering the operations inefficient and unsustainable (Roelich et al., 2015; Wei et al., 2018). Nonetheless, for long-term sustainability to be achieved, infrastructure needed to be operated in such a manner that it would be able to provide essential service delivery with minimal resources (Hui et al., 2018). Long-term sustainability was defined by Pardo-Bosch and Aguado (2016) as having adequate supply to meet the prevailing demand while ensuring that future generations would also meet their own needs. Even then, for a system to be sustainable it still had to possess some integrity (Leclert et al., 2016).

Study area

This paper reports on a study that was done to evaluate the service interruption frequency for the Umzinto Water Supply Scheme (UWSS), which is a potable water system that is situated in the Middle South Coast of Kwa-Zulu Natal (KZN) Province, South Africa. The Middle South Coast region extends along the Indian Ocean coastal strip from Mkomazi River southwards to the Umtwalume River. This region falls under the Umdoni Local Municipality (Umdoni LM), which is one of the local municipalities under Ugu District Municipality (Ugu DM) (Figure 1). This paper focused on all the areas that are supplied by the Umzinto Water Supply System as shown in Figure 2. According to the information from Statistics SA, the different areas that are supplied by the UWSS had approximately 57,740 people. This means that there were about 57740 people who were receiving water from the system either through private connections, public standpipes or illegal connections. All these people needed to be taken into consideration because they were using water from the system.

Water quality

The Umzinto WTW received water from the Umzinto Dam and EJ Smith Dam. The EJ Smith Dam had experienced a number of water quality failures. This was due to high *Escherichia coli* counts, which were an indication of sewage pollution. Two possible sources of pollution were identified as the wastewater pump station and solid waste, which was not well managed at the informal settlements, and both sources were situated above the dam. Despite these threats, the final water quality was always maintained within the South African National Standard (SANS 241:2015) guidelines resulting in the water being safe to drink. There was a high risk of turbidity in some reservoirs due to inadequate cleaning. Sediments that had settled in the reservoir floor were disturbed during peak periods leading to increased turbidi ty. However, the final water quality was still within the SANS 241:2015 standards.

Water availability in the Umzinto Water Supply System

The Umzinto WTW could produce up to 12 Ml/day; however, the demand in this system was always above the available supply.

Figure 3 shows the average daily demand (ADD), peak daily demand (PDD) and annual

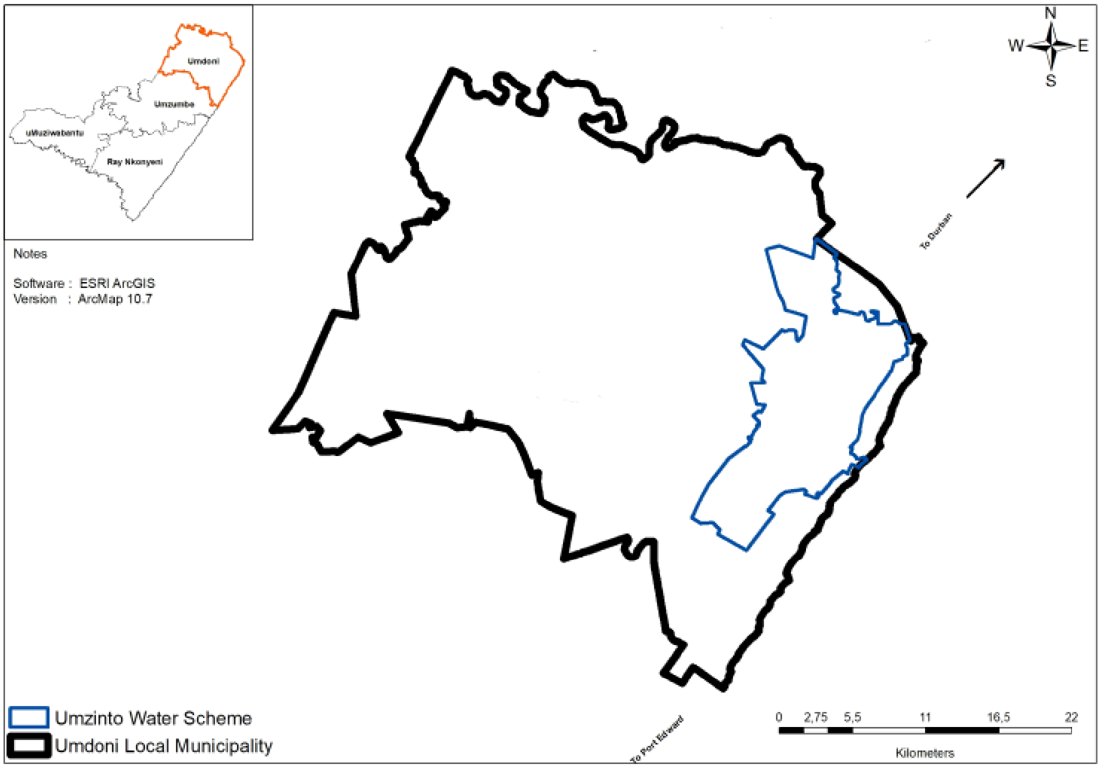

Figure 1. Ugu DM with Umdoni Local Municipality and Umzinto Water Scheme.

average daily demand (AADD) for the Umzinto Water Scheme. All these figures indicated that the treatment works was operating above its capacity especially during peak periods. Operating the treatment works above capacity had a negative impact on the water quality, infrastructure, system pressure and flow. The system was also expected to operate for more hours than it was designed to, in order to keep up with the demand. This was putting considerable strain on the infrastructure, and as a result, more chemicals had to be used in the treatment process. Occasionally, the South Coast Pipeline (SCP) boosted the Umzinto WTW with 3.5 Ml/day of treated water. From the SCP the water was pumped at Ellingham pump station to the Umzinto WTW.

LITERATURE REVIEW

Water supply

A study by Samir et al. (2017) emphasized that there was a global interest in studying the causes of leakage in water distribution systems (WDSs) and increased education on the importance of reducing the amount of leakage. This study noted that pressure management, by means of installing pressure reduction valves, had been successful in reducing leakage in WDSs. According to Martínez-Santos (2017), reliability in terms of water supply was another important factor that needed to be ensured. A number of issues contributed to the water supply being unreliable including ageing infrastructure and the infrastructure being situated away from urban centres, which were not easily accessible. A study by Mikovits et al. (2018) argued that major cities had been experiencing a growing urbanization trend, which had led to the rapid development of urban infrastructure such as water supply and wastewater systems. This study further stated that these systems were outdated and needed to be refurbished to prevent failure incidents in the future. Whilst this was indeed the case, some municipalities were experiencing an economic decline, which had resulted in a decreased tax base for sourcing maintenance funds. This had occurred mostly in cases where residential units had been demolished in a city, which had left the operations of the wastewater system and the provision of water at risk.

Water supply interruption

Water supply interruptions were mostly triggered by leakages in the distribution network or might also be due

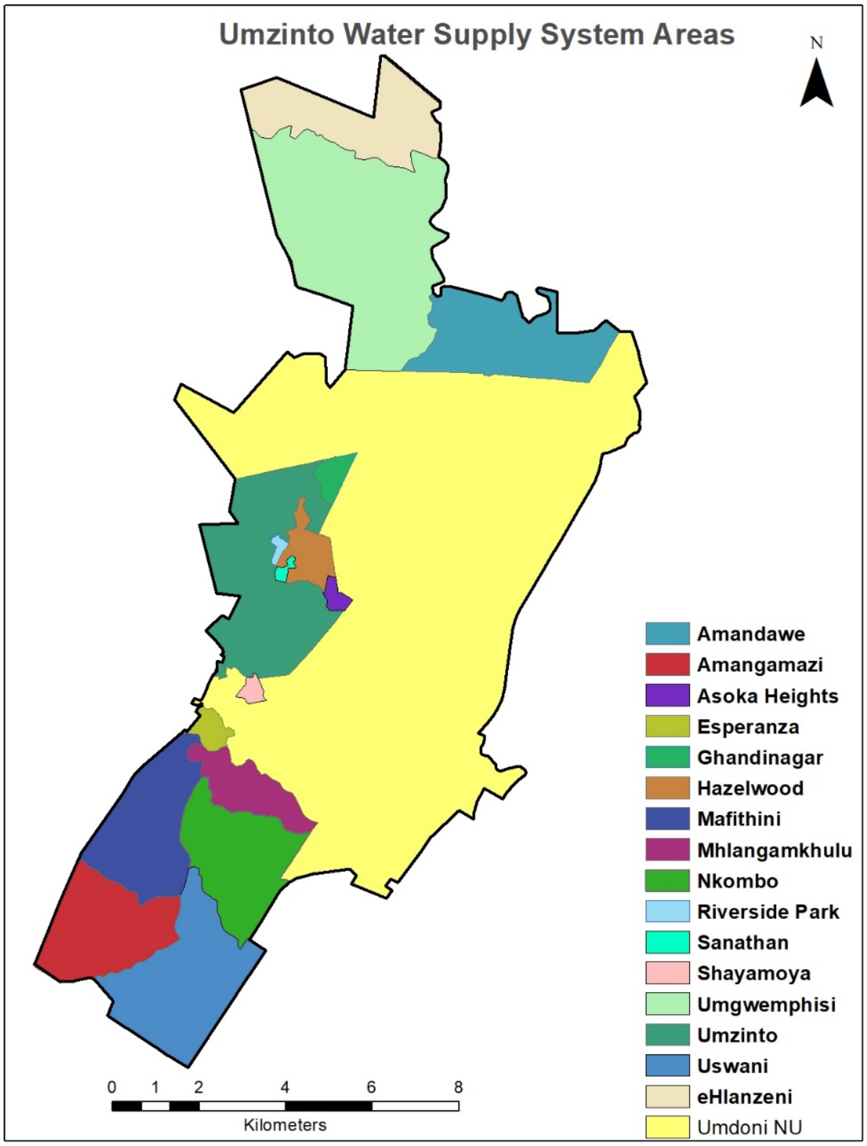

Figure 2. Umzinto water supply system areas.

to water scarcity. These interruptions might decrease in the rainy season due to the improved availability of surface water for the WTW. They directly affected consumers and Molinos-Senante and Sala-Garrido (2017) recommended that consumers should be compensated accordingly. However, the study also noted that some water managers had implemented compensation policies despite the difficulty in determining the price of compensation to consumers. On the other hand, it had to be noted that water service providers supplied drinking water in monopoly administrations, leaving consumers with very little choice as they did not have any options if they were not satisfied with the service. However, Roibas et al. (2018) suggested that the option of using a rationing method should be selected provided that the influence on consumer satisfaction during the implementation of the rationing plan was taken into consideration.

Some rationing systems could be described as deviations in terms of time taken for water availability but this did not change the planned consumer budget. On the other hand, Breyer et al. (2018) noted that water consumption could be limited by restricting outdoor water usage to address this problem. Subsequent to this, the assessment of the effect of limiting consumption was encouraged in order to develop a reliable rationing scheme. However, some approaches that were implemented to manage water usage, such as supply

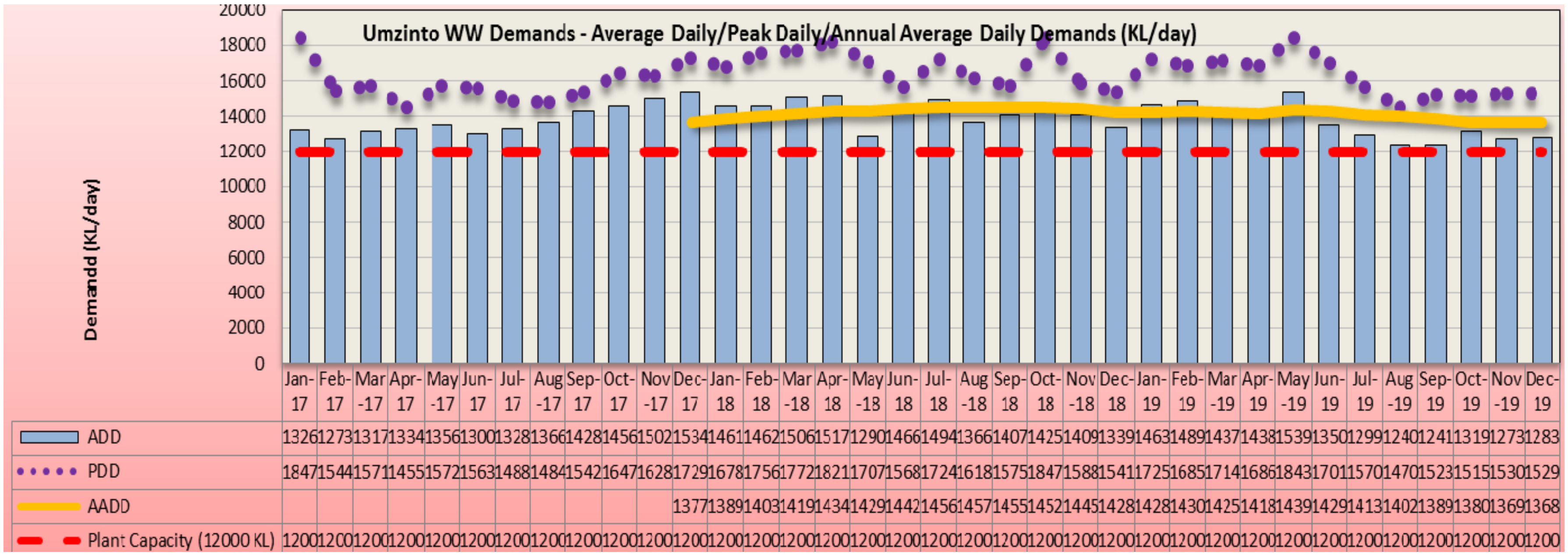

Figure 3. Umzinto WTW Demands - Average Daily/Peak Daily/Annual Average Daily Demands (KL/day). Source: Umgeni Water files.

cuts, were not simple to assess as they did not have an impact on the planned consumer budget.

Wang and Davies (2018) reported that the characteristics of water supply safety improvement included water charges, the quality of drinking water, disruption to supply, water supply pressure and water supply service. Consumers did not have a problem paying more than usual to improve the water supply pressure, reduce water supply interruptions and improve water supply service. This was because consumers wanted a reliable water service where the supply was continuous and there was adequate pressure. An uninterrupted water supply coincided with reduced spread of waterborne disease in the higher-risk parts of the population (Adane et al., 2017).

Intermittent water supply (IWS)

The O&M of the WDS was important for sustainable development, ensuring that there was no interruption in the supply of services and also to reduce water losses (Morais and de Almeida, 2007). Research by Brocklehurst and Slaymaker (2015) indicated that for water quality not to be compromised, the households should have a continuous supply of treated water accompanied by improved sanitation services. In support of this, findings by Roushdy and Sicvcrdiin (2016) suggested that the IWS options were controlling the health impacts that were being noted as a result of discrepancies in the water quality. These water supply interruptions could be reduced by the technical renewal of pipelines, replacement of old infrastructure, leak detection, pressure management in the network, proper design and construction and operation of the water supply system (Pietrucha-Urbanik, 2015).

According to Molinos-Senante and Sala-Garrido (2017), good quality service to customers was critical and therefore the prevention of unplanned interruptions required more investment. Notwithstanding this, Erickson et al. (2017) stated that unplanned interruptions could lead to IWS. Adane et al. (2017) noted that IWS might increase domestic water storage times, threaten hygiene practices and spread waterborne diseases. Because IWS caused considerable inconvenience to customers, Molinos-Senante and Sala-Garrido

(2017) recommended that they should be compensated accordingly; however, it was not easy to estimate the compensation fee payable to customers.

According to Del Saz-Salazar et al. (2016), water resources conservation was essential in order to attain sustainable development. Sustainable development was defined by Trudeau et al. (2018) as an uninterrupted provision of service, not merely access to service. However, due to water scarcity, rationing was sometimes implemented. While that might be the case, the implementation of a rationing strategy should be done based on the impact that the rationing plan had on consumer welfare (Roibas et al., 2018). Water rationing sometimes had a negative impact on the health of consumers. This was reported by Taylor et al. (2018) who stated that intermittent water was often contaminated and the contaminants were flushed into customers' homes when the system became pressurized.

According to Ercumen et al. (2015), intermittent distribution of piped water might lead to waterborne diseases caused by infection in the pipelines. Some countries which faced water scarcity problems implemented IWS policies as a way of controlling and conserving their natural resources (Agathokleous et al., 2017). On the other hand, the execution of such policies affected the performance of the system during the operation phase. Pihljak (2014) reported that during the operation stage, the gap between production and demand might cause an IWS provision in the system. While some consumers might receive an uninterrupted supply, others might experience intermittent supply or even an absence of water (Alda-Vidal et al., 2018).

Leakage management in a water distribution system

Leakage was one of the critical matters to be managed in order to enhance the effectiveness and efficiency of a WDS and to ensure that there was a continuous supply. A study by Xu et al. (2014) noted that water leakage was a waste of resources and substantial socioeconomic expenses were also incurred due to leakage. The improvement of leakage detection skills through pipe maintenance and pressure management could assist in reducing the leakages in a WDS. According to a study by Mutikanga (2012), reducing leakages in a WDS could lead to improved system performance, increased lifespan of assets and a saving of water resources. If not addressed, all these issues could lead to an interrupted supply of services.

Berardi et al. (2015) recommended water pressure management as an efficient and effective way to cut the leakage in a WDS and identified it as the main technique to stop background leakage which could not be detected by leakage detection methods. The management of pressure to the ideal levels of service in a WDS was critical in ensuring a satisfactory and effective water supply to consumers. A study by Lambert and Thornton (2011) revealed that pressure management had been used to control losses from supply networks for many years but researchers had now taken this further to explore how the frequency of pipe bursts changed with pressure.

The various benefits of pressure management, according to Lambert and Fantozzi (2010), were the reduction of water losses, improved customer service due to better service reliability, fewer water supply stoppages, decreased number of interruptions of water supply, prolonged lifespan of infrastructure, reduced consumption from pressure-related usages and rescheduling of infrastructure refurbishment and development. While the pipe network might have been designed and installed to meet the needs of difficult situations, leakages could not be avoided in a pipeline throughout the lifespan of a system (Abdulshaheed et al., 2017). On the other hand, Di Nardo et al. (2018) reported that the network could be simplified by developing District Metered Areas (DMAs) so that pressure management and leak detection could be done quickly and easily thus reducing the water supply interruption period. Findings by Kilinç et al. (2018) concluded that operating factors such as aged pipes, high pressure and constant water interruptions were the cause of pipe breakdowns.

Ageing infrastructure

For any country to achieve its target around economic growth and a reduction in poverty, it was important for water infrastructure to have adequate capacity and receive adequate maintenance for sustainability (Dadson et al., 2017). Most of the current water and wastewater infrastructure was of varying ages and in varying conditions, while most were simply too old. Old age was one of the reasons for infrastructure breaking down more often thus causing supply interruptions. Hukka and Katko (2015) reported that by 2012, there was an 85% access to potable water in urban areas and 53% access in rural areas, due to efficiency and operational problems, the real access figures were lower.

Al-Barqawi and Zayed (2008), in research that looked at infrastructure management, reported that the pace of deterioration of the main pipes in a WDS was influenced by environmental, operational and physical factors. Physical factors were the pipe material, age and wall thickness; environmental factors included soil type, soil humidity, ground water presence and climate and the operational factors were pressure leakage and breakage. All these factors could lead to IWS if they were not managed well. Deteriorating pipes could lead to ageing infrastructure which, according to Parlikad and Jafari (2016) required an increase in the amount of investment

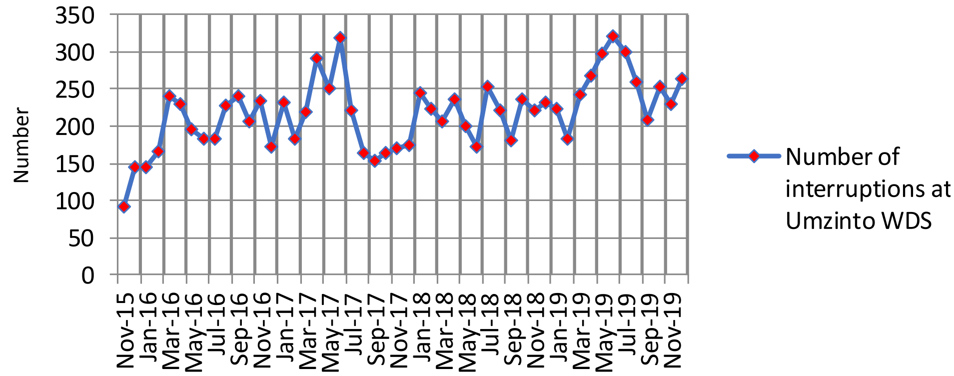

Figure 4. Water Supply Interruptions in Umzinto system from November 2015 to December 2019.

in upgrade and maintenance in order to ensure a continuous supply.

While this was a critical matter, Schlachter et al. (2011) raised concerns in a paper that looked at key challenges and strategies for local government that access to funding for water infrastructure was very difficult. On the other hand, Madumo (2015) advised that when there was inadequate funding, local government could not provide services because the ability to deliver constant and regular services became compromised. Since government could not offer the required funding to invest in increasing infrastructure needs, Nafziger and Koo (2015) recommended that municipalities should consider engaging the private sector for funding.

Water infrastructure funding

According to Rajé (2017), barriers to local financing of infrastructure were related to the nature of the projects available for investment, which often failed to meet the financing requirements of investors and a lack of available capital related to financial market conditions. Water projects were often difficult to fund because there was no guarantee of return on investment. Further to this, the residents needed to be educated to receive the development and ensure that the services were paid for. Musyoki and Gakuu (2018) reported that majority of the projects implementation has been unsuccessful due to a number of reasons like insufficient finances, poor conditions of infrastructure, political influence, poor technology and lack of community participation.

A study by Kodongo and Ojah (2016) revealed that a country could take part in accelerated and shared growth by investing in infrastructure. This was supported by Copeland et al. (2016) who provided strategic options, taking into consideration the budgets associated with funding water infrastructure. This study provided the options of developing a trust fund for water infrastructure, development of a state infrastructure bank or the lifting of limitations on private action bonds for projects that are related to water infrastructure.

The water industry was dealing with organizational and financial problems that had existed for far too long, resulting in a lack of funding and poor service delivery (Kolker et al., 2016). On the other hand, the absence of technical and financial competences had resulted in reduced revenue collections, high losses, substantial operating costs, lack of sound management and weakened operating effectiveness and had restricted the industry's capacity to obtain alternative funding sources (Arezki et al., 2017).

While the inadequate distribution of financial resources was known to be a challenge in developing countries, the replacement of water infrastructure involved huge capital investment from the government (See and Ma, 2018). As various developing countries dealt with excessive financial limitations, it was a challenge for them to obtain a reliable source of funding, leading to underinvestment of key infrastructure (Rillo and Ali, 2018). Consequently, the current economic climate needed to be analyzed by investigating the barriers and challenges in municipal finance and the new sources of municipal finance that had to be obtained to promote greater infrastructure investment.

MATERIALS AND METHODS

The water supply failures as reported by the consumers and recorded in the fault management system per system were analyzed using the water supply scheme zones. This analysis included all the system failures, the frequency of the failures, the causes of the failures, how they were resolved, and both the short-term and permanent solutions. An analysis of the causes of the failures and how they were resolved was obtained from the job cards. From this information short-term and permanent solutions were developed. This was done by locating the position of the failures, and the frequency and the causes of these failures.

shows the number of interruptions that were recorded by the municipality during the period from November 2015 to December 2019. The Ugu DM implemented a fault management system from November 2015 and that was where all the data was obtained. The system that was used before November 2015 crashed, losing all the data.

Each incident in the system was analyzed and compared with the job card to determine the cause of these interruptions. The job cards had recorded the details of what the field team found on the ground, how they managed to resolve the problem and the material used to fix the problem. An analysis into the exact positions of the failures was also done in order to determine where the system had experienced challenges. It was noted from the analysis that the failures had occurred at the same locations. From the analysis, it became evident that the biggest cause of the interruptions had been the ageing infrastructure that needed to be replaced. This made sense considering that the majority of the infrastructure in the system was more than 30 years old. The replacement of the infrastructure needed a huge capital injection that the municipality did not have available.

An analysis was done using the information from the job cards to determine the solutions to the system failures. The system was also assessed for any planned maintenance of the infrastructure. This was done by analyzing the operations and maintenance plans to determine if they had been implemented accordingly. This was because planned maintenance could have prevented infrastructure failure, which had resulted in the interruption of the supply.

RESULTS AND DISCUSSION

Aging infrastructure

From the results, it was evident that most of the water supply interruptions were caused by ageing infrastructure that needed to be replaced. Most of the pipes in the system were more than 30 years old and were breaking frequently. The municipality needed to roll out an ageing infrastructure replacement programme that would include pipes, valves, standpipes and pumps but this would need huge capital investment. Overhauling old water infrastructure would ensure that future generations were supplied with safe clean water. Ageing infrastructure accounted for most of the water wastage through leaking pipes and pipe bursts. Augmenting infrastructure and refurbishing aged and obsolete infrastructure could result in better service delivery to customers across the system.

Table 2 shows a comprehensive breakdown of the supply interruptions in relation to the type of failure, cause of the failure and solution to the problem. The majority of the interruptions were caused by ageing infrastructure, which had been neglected over the past 25 years, and the effects of drought had exacerbated this. The rainfall patterns for South Africa show that the amount of rain received has decreased over the years, negatively affecting the water supply. The decrease in the available water supply decreases the chances of meeting the water demand.

SCADA and telemetry system

The faulty SCADA and telemetry system was also one of the causes of the water interruptions because it was impossible to remotely monitor the whole network without this system in place. The telemetry and SCADA system comprised data loggers connected to the infrastructure, sensors and centralization software. It was used to control and manage the system remotely. With this system, the network was managed better, and the operation of its devices could be optimized. The benefits of this system were savings in energy and swift leak detection. The benefit attained from remote monitoring and by alerting the personnel on standby duty to any automatic alarms would be improved service supplied to the consumers.

Standard repair procedure

There was also a need for a standard operating procedure (SOP) for the repairs of infrastructure. A number of complaints on quality of water were received per month despite the fact that the production of the treatment plant complied with SANS 241 standards. The common cause for this complaint was failure to flush the system after repairing a breakage. The other challenge that was noticeable in the complaints was that the interruptions were reoccurring in the same section of the pipe. The maintenance team was not releasing the air lock in the system after resolving an interruption before the water started filling up the system and this had caused some of these recorded interruptions. The system operators were supposed to follow these basic procedures.

There was another category of failure where the interruption of the supply lasted for a long period of time. It had been noted that this category was usually caused by the maintenance team not following standard procedure when opening and closing valves in the system. In several instances there had been no proper handover between the teams in the field. A team would close the valve while resolving an interruption and when the next team came on duty they would take days to identify the problem. Sometimes a valve that was meant to be kept closed would be left open, allowing the water to flow along the wrong pipeline route. When the researcher was studying the job cards it was noted that this was happening quite often.

The other challenge noted was that there was no documented operating procedure for the system. This meant that each system operator on duty operated the system in a different way. This meant that the trouble shooting exercise during system failures took much longer than it should have. The system had critical points that needed to be considered in the event of a failure but these finer points were not fully understood by all the members of the maintenance teams. Ideally, there should have been a documented systematic operational procedure for the system.

Table 2. Detailed breakdown of the supply interruptions in the Umzinto water supply system.

Type of failure	Cause of failure	Solution
Burst pipes	Ageing infrastructure	Replacement of infrastructure
Leaking pipes	Ageing infrastructure	Replacement of infrastructure
Leaking Meter/Faulty Meter/Meter Change	Ageing infrastructure	Replacement of infrastructure
Activation of services	Faulty or non-existence of telemetry system	Installation of the SCADA (Supervisory Control and Data Acquisition) and telemetry system
Standpipe leaking	Ageing infrastructure/vandalism	Consumer awareness campaigns
Reservoir level low	Unforeseen burst/leak in the system	-
No water	Burst pipe	Replacement of infrastructure
Low water pressure	Burst pipe	Replacement of infrastructure
Reservoir overflow	Faulty level control valve	Replacement of infrastructure
Water dirty out of taps	Inadequate flushing after repair	Flushing of the system after repair
Valve failure	Ageing infrastructure	Replacement of infrastructure
Other	System unbalanced and needing physical balancing	Installation of the SCADA and telemetry system
Pump station faulty	Mechanical and electrical faults	Regular maintenance of infrastructure
Illegal connections	Illegal connection to the municipal system	Legalise the connections and register the customer details in the billing system

Mechanical and electrical faults

Mechanical and electrical faults were also occurring frequently. This was because most of the pumps were old and had not been maintained on a regular basis. According to the maintenance plan, each running pump was supposed to have a standby pump in case of a breakdown but most pump stations did not have these standby pumps. The pumps were running 24/7 until they failed and the teams would start looking for replacements after failure. Although this was part of the maintenance plan it was not included during the budget process. For example, there was no dedicated budget for the Umzinto system; the budget was lumped together with other systems and was insufficient. The budget allocated for maintenance was less than the required budget to ensure adequate O&M. It was also discovered that the operational budget was the first to be cut when the municipality faced financial difficulties.

Illegal connections

Illegal connections were another challenge faced by Ugu DM. The system was found to have leaks due to illegal connections that were not properly connected to the system. The municipality did not have a solution to this challenge. The most common form of illegal connection identified in the rural areas was where the residents extended their connections from a single standpipe connection. In urban areas where there were private connections, residents had bypassed the meter and some had removed the meter. This meant that the system would always experience a higher demand than it should, thus putting strain on the whole system.

Replacement of AC pipes

As a rural municipality, Ugu DM was faced with the challenge of reducing the huge backlog whilst replacing the ageing infrastructure. The problem with the ageing infrastructure was that once it began breaking down, repairing it time and again did not solve the problem as it continued to break down until it was replaced. For instance, from the schematic drawing it was clear that the system still had old Asbestos Cement (AC) pipes. Once this type of pipe started breaking, it did not stop so the whole length of the pipe would have to be replaced. AC pipes were mostly used when the system was built approximately 30 years ago. The water infrastructure from the treatment plant to Umzinto CBD was installed over 30 years ago and was one of the first water systems constructed in Umdoni Local Municipality. This infrastructure had reached its lifespan. Moreover, the AC pipes were brittle, and the frequency of interruptions was exacerbated by the extreme weather conditions, particularly because of expansion and contraction. Figure 6 to 8 show the exact positions of each

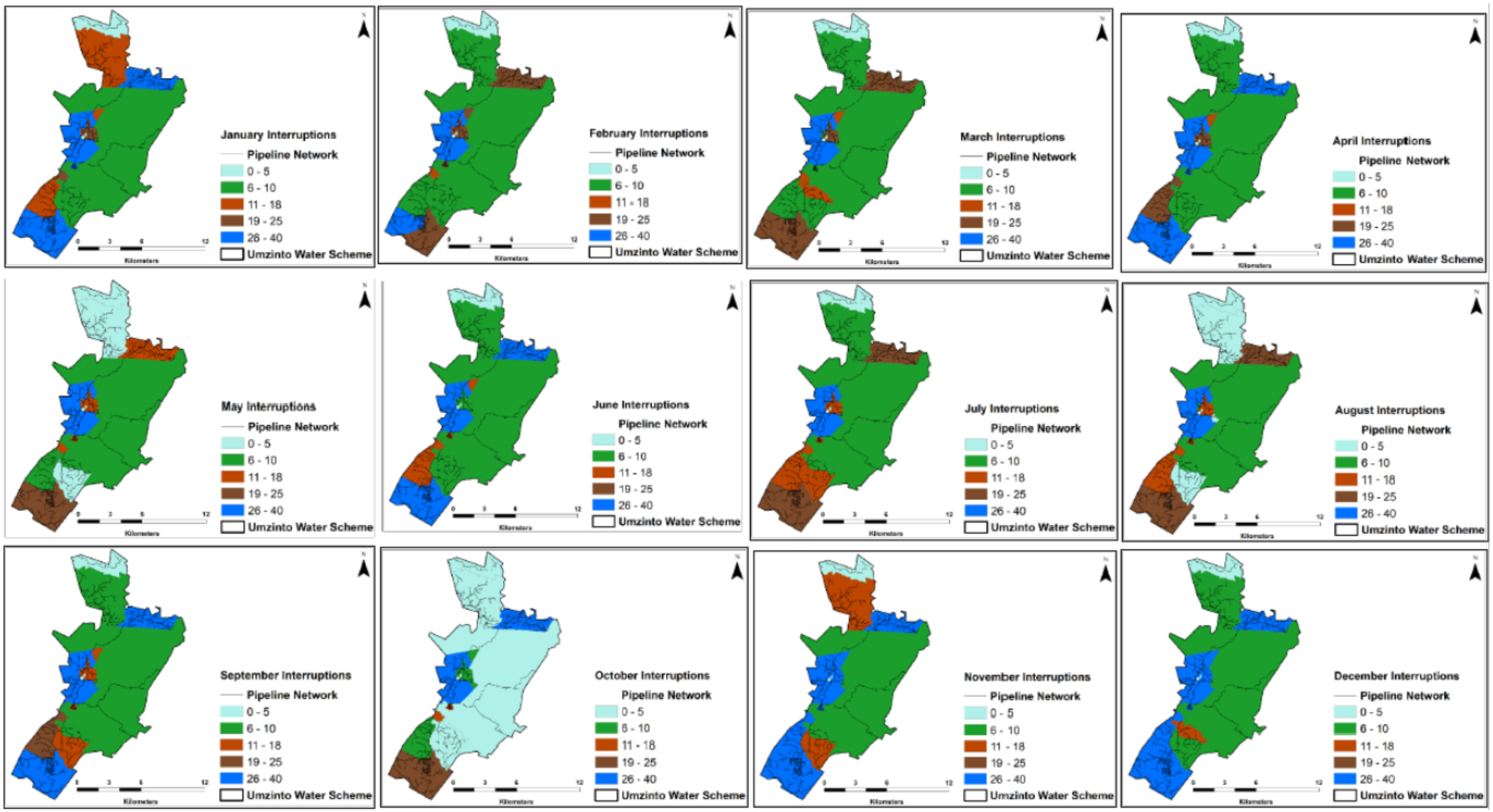

Figure 5. Frequency of water supply interruptions in the Umzinto system in each month of 2016.

interruption in the Umzinto supply system during the years 2016, 2017, 2018 and 2019, respectively. The spatial trends show that the interruptions were repeatedly taking place around the same positions. These failures left residents and businesses around the Umzinto without water. Ugu DM is a tourist destination, which would have been very busy during the school holiday seasons. The temporal trends show the behavior of the system during the various seasons of the year. January was a busy month although many people started going back to their respective areas mid-

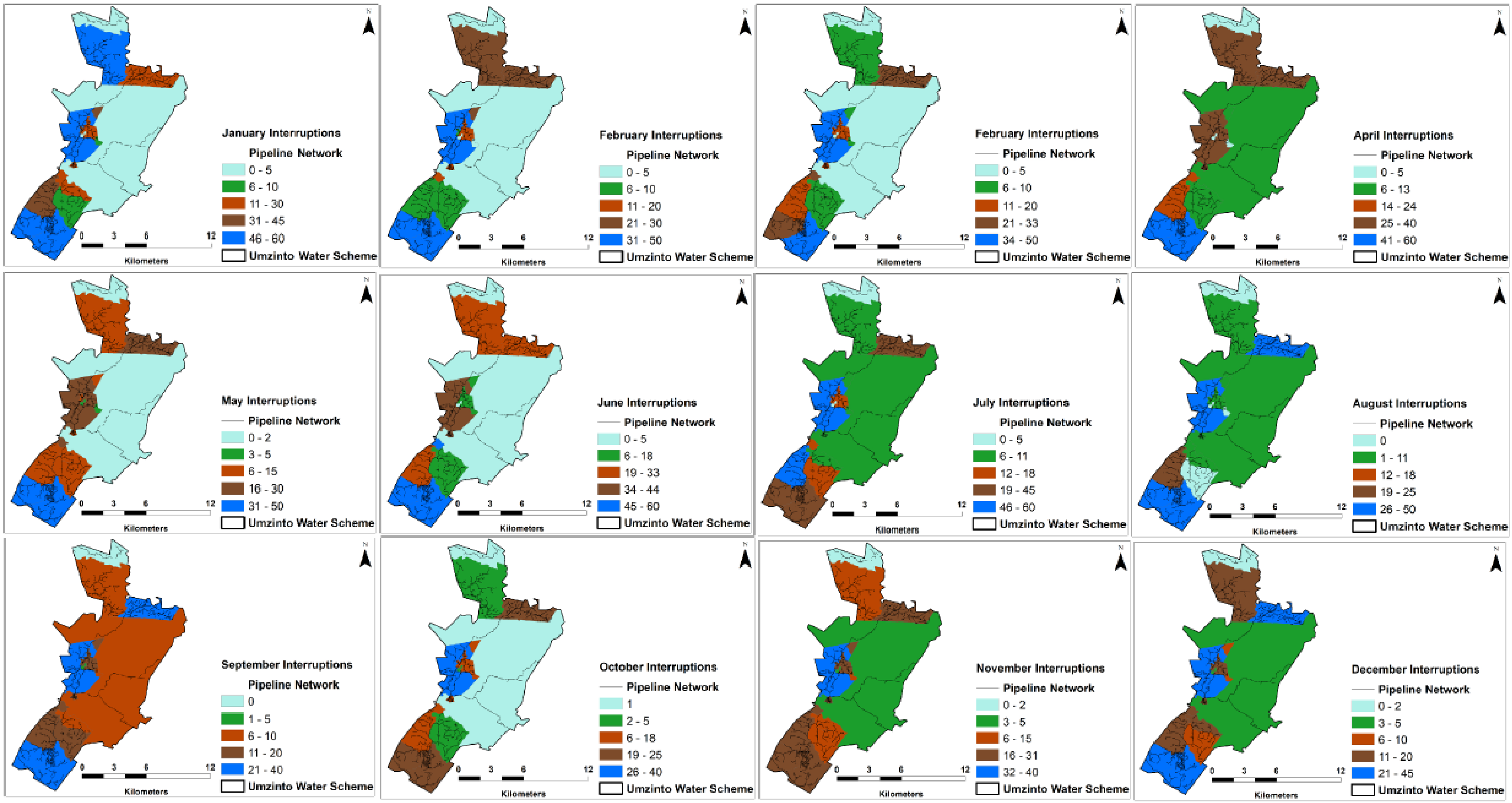

Figure 6. Frequency of water supply interruptions in the Umzinto system in each month of 2017.

January when the schools were opening, but the interruptions were high around Umzinto town. February and March saw the interruptions starting to go down because these are off-season months. In April, the interruptions started going up again with the system under pressure due to increased demands as a result of the school holidays and holidaymakers visiting the area. The demand decreased in May resulting in reduced interruptions but when the winter season started in June, the interruptions started going up again with the system under a lot of pressure.

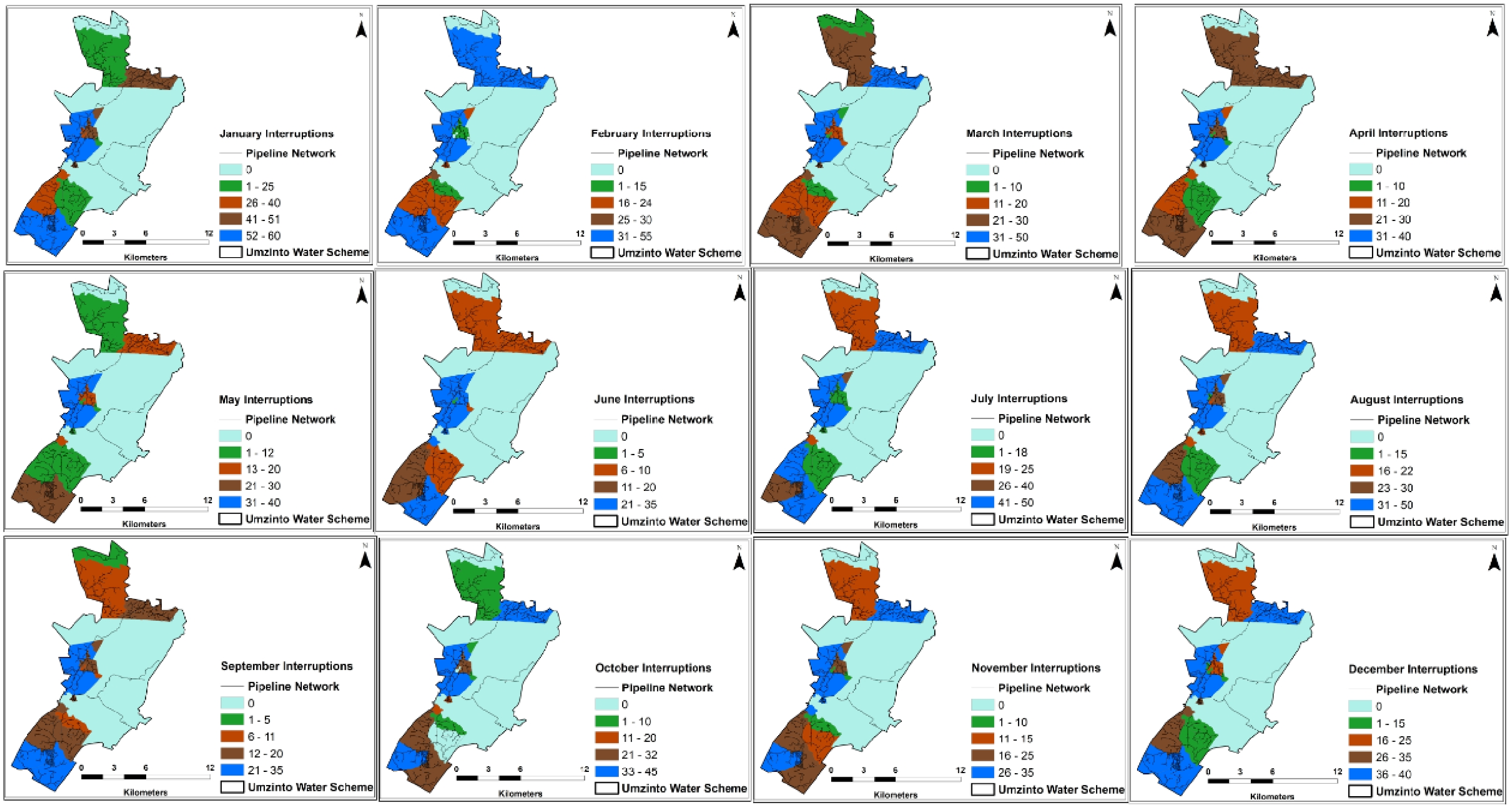

Figure 7. Frequency of water supply interruptions in the Umzinto system in each month of 2018.

The other cause for high interruptions in winter was that there was inadequate rain to supply the system and the operations team had to balance the system supply by applying water shedding resulting in interruptions. All the summer months had a high number of interruptions because the demand was very high due to the increased number of people in the area. The system had old pipes which caused interruptions more often when put under pressure resulting in water supply interruptions.

Figure 5 shows that the area that experienced a high number of interruptions throughout the whole year was Umzinto town. Umzinto town shows a high number of interruptions in the whole twelve

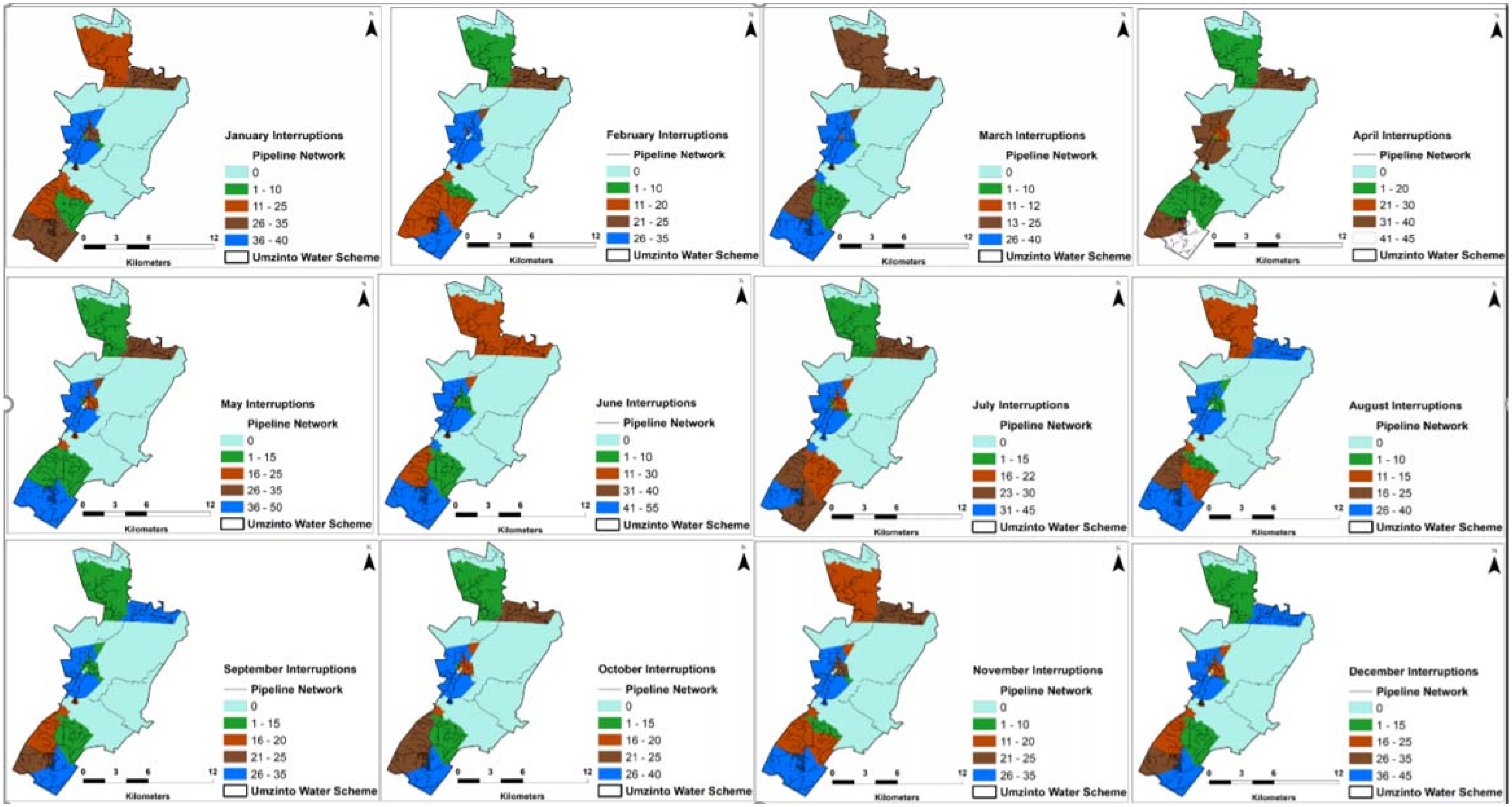

Figure 8. Frequency of water supply interruptions in the Umzinto system in each month of 2019.

months. This is because the infrastructure at of January is usually very busy in Umzinto system because the most holidaymakers start leaving in the third week of January 2016.

Umzinto twon is old and therefore very fragile. In the month of January 2016, most interruptions were experienced in Amandawe, Umzinto town, Amangamazi and Uswani areas. There were also high interruptions experienced in Hazelwood the most number of interruptions followed by Amandawe, Uswani and Amangamazi areas. In April 2016, the during the month of January. The beginning.

In February 2016, most interruptions were experienced in Umzinto town and Amangamazi areas followed by Amandawe, Hazelwood and Uswani areas. March 2016 saw Umzinto town with highest number of interruptions was experienced in Uswani, Amangamazi and Amandawe areas. Mafithini and Hazelwood areas also experienced a high number of interruptions, during this month.

In May 2016, Umzinto town experienced the highest number of interruptions followed by Uswani, Amangamazi, Shayamoya and Amandawe areas.

In June 2016, there were high number of interruptions experienced in Umzinto town, Uswani, Amangamazi and Amandawe areas followed by the Shayamoya area. During the month of July 2016, the highest number of interruptions in the system was in Umzinto town followed by Uswani, Amangamazi and Amandawe areas. During the August 2016 period, the highest interruptions in the system were in Umzinto town. In September 2016, the highest interruptions were experienced in Umzinto town, Uswani, Amangamazi and Amandawe areas. In October 2016, there were high interruptions in Umzinto town and Amandawe areas while in November 2016, the most interruptions were experienced in Umzinto town, Uswani, Amangamazi, Mafithini and Amandawe areas. In December 2016, the highest interruptions were in Umzinto town, Uswani, Amangamazi and Amadawe areas.

Figure 6 shows the frequency of the water supply interruptions that were experienced in the Umzinto system in each month of 2017. In January 2017, the most interruptions were experienced in Umzinto town, Uswani, Amangamazi and Umgwempisi areas. In February 2017, the highest interruptions in the system were in Umzinto town, Uswani and Amangamazi areas. In March 2017, there were high interruptions at Umzinto town and Uswani area while in April 2017, the highest interruptions were in Uswani and Amangamazi areas. In May 2017, the most interruptions were experienced in Uswani and Amangamazi areas.

In June 2017, the highest interruptions were in Uswani, Amangamazi and Esperanza areas. In July 2017, the highest interruptions were in Umzinto town and Mafithini areas. In August and September 2017, the highest interruptions were in Umzinto town, Uswani, Amangamazi and Amandawe areas. October and November 2017, saw the highest interruptions experienced in Umzinto town while December 2017, had the highest interruptions experienced in Umzinto town, Uswani, Amangamazi and Amandawe areas.

Figure 7 shows the frequency of the water supply interruptions that were experienced in the Umzinto system in each month of 2018. In January 2018, the most interruptions were experienced in Uswani, Amangamazi and Umzinto town. In February 2018, the most interruptions were experienced in Uswani, Amangamazi, Umzinto town, Amandawe and Umgwempisi. In March 2018, the highest interruptions were experienced in Umzinto town and Amandawe areas. In April and May 2018, the highest interruptions were experienced in Umzinto town.

In June 2018, the most interruptions were experienced in Umzinto town, Uswani and Esperanza areas. In July 2018, the most interruptions were experienced in Uswani, Mafithini, Umzinto town and Amandawe areas. In August 2018, the most interruptions were experienced in Uswani, Amangamazi, Umzinto town and Amandawe areas. In September 2018, the most interruptions were experienced in Uswani, Amangamazi and Umzinto town. In October and November 2018, the most interruptions were experienced in Amangamazi, Umzinto town and Amandawe areas. In December 2018, the most interruptions were experienced in Uswani, Amangamazi, Umzinto town and Amandawe areas.

Figure 8 shows the frequency of the water supply interruptions that were experienced in the Umzinto system in each month of 2019. In January 2019, the most interruptions were experienced in Umzinto town, which has industries that are busy during the holiday season. In February 2019, the most interruptions were experienced in Uswani and Umzinto town. In March 2019, the most interruptions were experienced in Uswani, Amangamazi and Umzinto town. In April 2019, the most interruptions were experienced in Amangamazi, Esperanza, Umzinto town and Amandawe areas, while in May 2019, the most interruptions were experienced in Uswani, Amangamazi and Umzinto town.

During the month of June 2019, the most interruptions were experienced in Uswani, Amangamazi, Esperanza and Umzinto town. In July 2019, the most interruptions were experienced in Amangamazi, Esperanza and Umzinto town. In August 2019, the most interruptions were experienced in Uswani, Amangamazi, Umzinto town and Amandawe areas. In September 2019, the most interruptions were experienced in Uswani, Umzinto town and Amandawe areas. In October 2019, the most interruptions were experienced in Uswani, and Umzinto town. In November 2019, the most interruptions were experienced in Uswani, Amangamazi and Umzinto town while December 2019, saw the most interruptions experienced in Uswani, Umzinto town and Amandawe areas.

The areas with the highest number of interruptions were Umzinto town, Amandawe, Uswani and Amangamazi areas. These areas had the highest number of interruptions throughout the year. The infrastructure in these areas was old and needed to be replaced as a matter of urgency. Most of the pipelines were more than 30 years old and the system had experienced varying pressure in these areas. There was thus an urgent need for the ageing infrastructure in these areas to be replaced. The lack of planned maintenance for this infrastructure had led to it deteriorating to a level where it had become too expensive to maintain and repair and the only sustainable solution was thus replacement.

There was a dire need for a replacement programme, which would include the upgrading of the ageing pipelines. The old AC pipes could be replaced with a uPVC (plastic) pipeline which had proved to be more suited to the local soil conditions. In areas where the AC

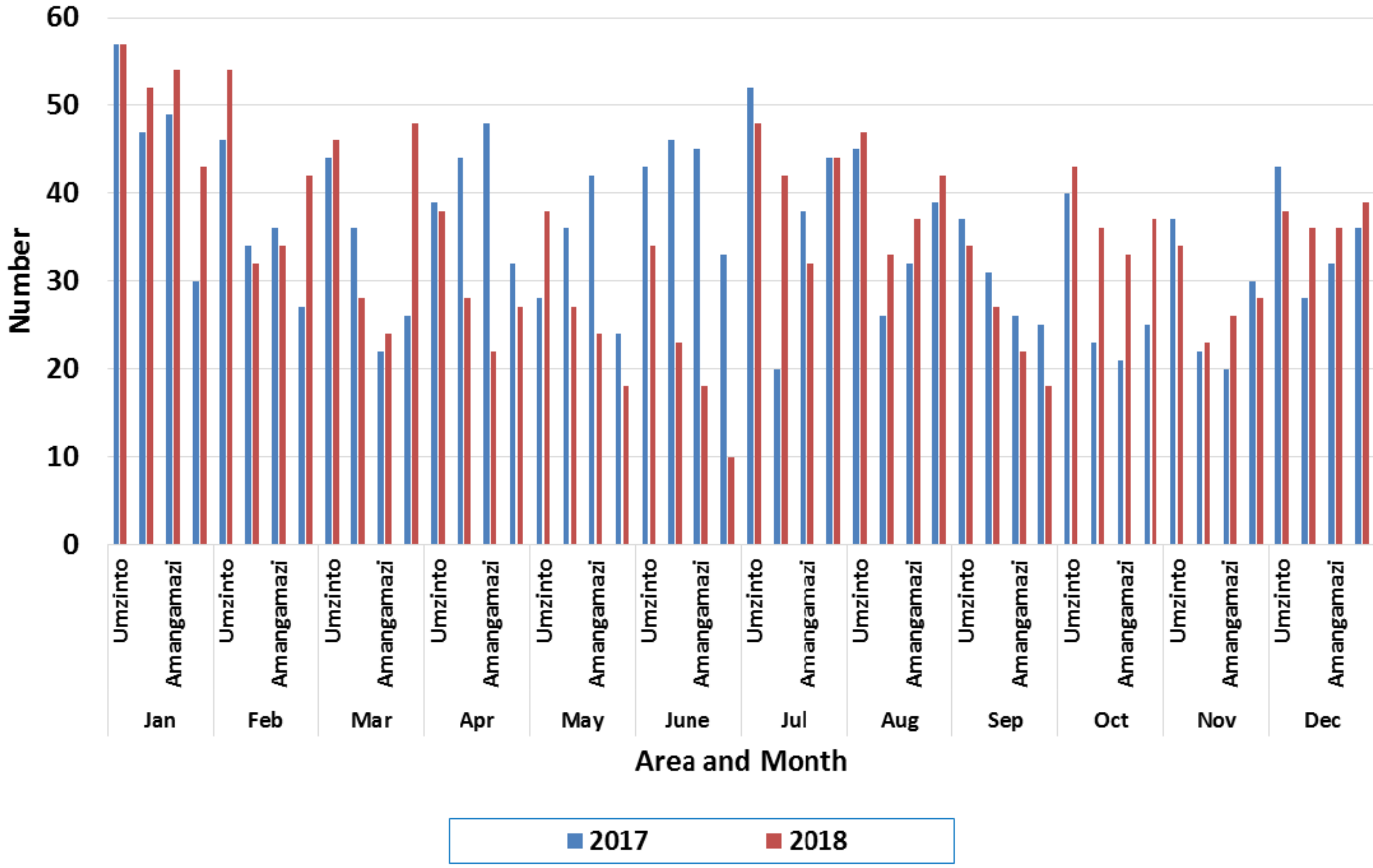

Figure 9. Comparison of the water supply interruptions in Umzinto, Uswani, Amangamazi and Amandawe areas.

pipes had been replaced, the number of interruptions had significantly decreased. Spot fixing only acted as a band-aid to the infrastructure problem and was not a sustainable solution; replacement would be the best solution in most cases.

Over and above the aged infrastructure, the other challenge with Amandawe, Uswani and Amangamazini areas was that they had inadequate storage. This meant that after each system failure, these areas would take a long time to recover, leaving the community frustrated and calling the municipality reporting water challenges, which explained the high number of complaints during those times. The solution for these areas would be to construct reservoirs to create storage. It was noted that the spatial and temporal trends had been almost the same for the four years of the study.

It was also noted that the municipality did not undertake planned maintenance but only did reactive maintenance. Planned maintenance is sometimes referred to as preventive maintenance and it is a form of regular maintenance undertaken on infrastructure to avoid breakdowns. This meant that if this routine maintenance was inadequate, the infrastructure was likely to experience interruptions. The municipality urgently needed to start implementing planned maintenance to increase the lifespan of the infrastructure. Due to a lack of planned maintenance, the municipality spent unnecessary time dealing with the consequences of system failures instead of managing production.

Planned maintenance would also assist the municipality to avoid incurring costs when operations were interrupted. This was because it is far more cost effective to keep the system in operating condition than to do major replacements as minor failures could lead to major malfunctioning. The other challenge was that without preventive maintenance the infrastructure operated at a reduced rate of efficiency until it broke down completely. During these breakdowns, operations would come to a standstill and the employee costs become unnecessarily high.

Figure 9 shows the comparison of the water supply interruptions in Umzinto, Uswani, Amangamazi and Amandawe areas, which are the areas with the most number of interruptions. The comparison was done between the two years, 2017 and 2018. Overall, 2017 had more interruptions in these areas that the ones experienced in 2018. These four areas experienced the highest number of interruptions in all seasons of the year. January in both years experienced very high interruptions in all four areas. There was a slight decrease in numbers in February in the other areas but Umzinto remained high. March saw a further decrease especially in Amangamazi area more than the others. April saw an increase again for both years but there was a steep increase in Amangamazi area especially in 2017. Amandawe area experienced the lowest interruptions in both years during the month of May and June. These were the winter months and the schools were still open.

Umzinto had the highest number of interruptions in both years from July to October. July is a holiday month and often experiences high water demands due to holidaymakers in the area. With the increased demands, the system experienced high pressures, which the fragile infrastructure could not handle and started giving up. August to September is very hot in the South Coast and usually see high water usage thus putting pressure on the already fragile system. This indicates that there is a huge demand for water conservation awareness to the consumers. There was a decrease in the numbers for Uswani and Amangamazi in the month of November for both years but there was an increase again in December, which is the busiest month in the system.

Conclusion

The spatial maps developed using the information from the fault management system of the municipality, showed that the interruptions were generally taking place in all parts of the supply system, but more frequently in Umzinto town, Uswani, Amangamazi and Amandawe areas than the other areas. This showed that there were weaknesses in the system and specifically in the areas where there were frequent failures, resulting in supply interruptions. The municipality needs to develop a plan to reduce the failures in the system thus ensuring an uninterrupted supply of water to the people. The plan should address the ageing infrastructure, standard repair procedure, illegal connections and high flow pressure.

Although there was a need for the replacement of ageing infrastructure in the system, some solutions to the bigger problem did not require capital investments. These included consumer awareness programme, consumer enumeration and connection, billing and collection and routine maintenance. These were some of the interventions, which were needed in the system to improve the supply. Well-informed consumers are always an advantage to the municipality because they improve water use efficiency and the revenue collection.

The spatial and temporal trends show that there are areas, which should be given priority during the interventions. Although the interruptions were experienced throughout the year, but the summer period, which is October to January, experienced very high numbers of interruptions as compared to the rest of the year. The month of June, which is, the beginning of the winter holidays also experienced high numbers of interruptions in the system. The areas with high numbers of interruptions during the whole study period were Umzinto town, Amandawe, Uswani and Amangamazi.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors would like to thank the Durban University of Technology for hosting and funding this project. Ugu District Municipality is also sincerely acknowledged for providing data that was useful in completing this project. The BRICS multilateral R&D project (BRICS2017-144) and NRF UID number 116021 are acknowledged for providing funding to the student to enable exposure to hydrological modelling.

REFERENCES

Abdulshaheed A, Mustapha F,Ghavamian A (2017). A pressure-based method for monitoring leaks in a pipe distribution system: A review. Renewable and Sustainable Energy Reviews 69:902-911.

Adane M, Mengistie B, Medhin G, Kloos H, Mulat W (2017). Piped water supply interruptions and acute diarrhea among under-five children in Addis Ababa slums, Ethiopia: A matched case-control study. PloS One 12(7):e0181516.

Agathokleous A, Christodoulou C, Christodoulou SE (2017). Influence of intermittent water supply operations on the vulnerability of water distribution networks. Journal of Hydroinformatics 19(6):838-852.

Al-Barqawi H, Zayed T (2008). Infrastructure management: integrated AHP/ANN model to evaluate municipal water systems' performance. . Journal of Infrastructure Systems 14(4):305-318.

Alda-Vidal C, Kooy M, Rusca M (2018). Mapping operation and maintenance: an everyday urbanism analysis of inequalities within piped water supply in Lilongwe, Malawi. Urban Geography 39(1):104-121.

Arezki R, Bolton P, Peters S, Samama F, Stiglitz J (2017). From global savings glut to financing infrastructure. Economic Policy 32 (90): 221-261.

Berardi L, Laucelli D,Ugarelli R, Giustolisi O (2015). Leakage management: Planning remote real time controlled pressure reduction in Oppegård municipality. Procedia Engineering 119:72-81.

Bostick TP, Connelly EB, Lambert JH, Linkov I (2018). Resilience science, policy and investment for civil infrastructure. Reliability Engineering and System Safety 175:19-23.

Breyer B, Zipper SC, Qiu J (2018). Sociohydrological Impacts of Water Conservation Under Anthropogenic Drought in Austin, TX (USA). Water Resources Research 54(4):3062-3080.

Brocklehurst C, Slaymaker T (2015). Continuity in drinking water supply. PLoS Medicine 12(10):e1001894.

Copeland C, Mallett WJ, Maguire S (2016). Legislative Options for Financing Water Infrastructure. Congressional Research Service Report P 42467.

CSIR (2007). The state of municipal infrastructure in south africa and

its operation and maintenance. . Pretoria, South Africa.
Dadson S, Hall JW, Garrick D, Sadoff C, Grey D, Whittington D (2017). Water security, risk, and economic growth: Insights from a dynamical systems model. Water Resources Research 53(8):6425-6438.
de Graaf R, van der Brugge R (2010). Transforming water infrastructure by linking water management and urban renewal in Rotterdam.
Technological Forecasting and Social Change 77(8):1282-1291.
Del Saz-Salazar S, García-Rubio MA, González-Gómez F, Picazo-Tadeo AJ (2016). Managing water resources under conditions of scarcity: on consumers' willingness to pay for improving water supply infrastructure. Water Resources Management 30(5):1723-1738.
Di Nardo A, Di Natale M, Gargano R, Giudicianni C, Greco R, Santonastaso G (2018). Performance of partitioned water distribution networks under spatial-temporal variability of water demand. Environmental Modelling and Software 101:128-136.
Dong X, Du X, Li K, Zeng S, Bledsoe BP (2018). Benchmarking sustainability of urban water infrastructure systems in China. Journal of Cleaner Production 170 (Supplement C):330-338.
Ducrot R (2017). When good practices by water committees are not relevant: Sustainability of small water infrastructures in semi-arid mozambique. Physics and Chemistry of the Earth Parts A/B/C 102:59-69.
Ercumen A, Arnold BF, Kumpel E, Burt Z, Ray I, Nelson K, Colford Jr, JM (2015). Upgrading a piped water supply from intermittent to continuous delivery and association with waterborne illness: a matched cohort study in urban India. PLoS Medicine 12(10):e1001892.
Erickson JJ, Smith CD, Goodridge A, Nelson KL (2017). Water quality effects of intermittent water supply in Arraiján, Panama. Water Research 114:338-350.
Furlong C, Brotchie R, Considine R, Finlayson G, Guthrie L (2017). Key concepts for Integrated Urban Water Management infrastructure planning: Lessons from Melbourne. Utilities Policy 45 (Supplement C):84-96.
Grady CA, Weng SC, Blatchey ERI (2014). Global Potable Water: Current Status, Critical Problems, and Future Perspectives. Ecological Sciences and Engineering Program,
Hui R, Herman J, Lund J, Madani K (2018). Adaptive water infrastructure planning for nonstationary hydrology. Advances in Water Resources 118:83-94.
Hukka JJ, Katko TS (2015). Resilient Asset Management and Governance Fordeteriorating Water Services Infrastructure. Procedia Economics and Finance, 21 (Supplement C):112-119.
Kilinç Y, Özdemir Ö, Orhan C, Firat M (2018). Evaluation of Technical Performance of Pipes in Water Distribution Systems by Analytic Hierarchy Process. Sustainable Cities and Society 42:13-21.
Kodongo O, Ojah K (2016). Does infrastructure really explain economic growth in Sub-Saharan Africa? Review of Development Finance 6(2):105-125.
Kolker JE, Trémolet S, Winpenny J, Cardone R (2016). Financing Options for the 2030 Water Agenda.
Koop SH, van Leeuwen CJ (2015). Assessment of the sustainability of water resources management: A critical review of the City Blueprint approach. Water Resources Management 29(15):5649-5670.
Kuo YY, Cheng MH (2018). Budgeting and financial management of public infrastructure: The experience of Taiwan. Value For Money, p. 221.
Lambert A, Fantozzi M (2010).Recent developments in pressure management. In IWA Conference" Water loss 2010.
Lambert A, Thornton J (2011) .The relationships between pressure and bursts-a'state-of-the-art'update. Water 21(4):37-38.
Leclert L, Nzioki RM, Feuerstein L (2016). Addressing Governance and Management Challenges in Small Water Supply Systems – The Integrity Management Approach in Kenya. Aquatic Procedia 6:39-50.
Lester S, Rhiney K (2018).Going beyond basic access to improved water sources: Towards deriving a water accessibility index. Habitat International 73:129-140.
Madumo O (2015). Developmental local government challenges and progress in South Africa. Administration Publica 23(2):153-166.
Magombo J (2017). Synthesis of a model for optimising a potable water treatment plant and water usage analysis in the Ugu District.
Martínez-Santos P (2017). Determinants for water consumption from improved sources in rural villages of southern Mali. Applied Geography 85 (Supplement C):113-125.
Meissner R, Steyn M, Moyo E, Shadung J, Masangane W, Nohayi N Jacobs-Mata I (2018). South African local government perceptions of the state of water security. Environmental Science and Policy 87:112-127.
Mikovits C, Rauch W, Kleidorfer M (2018). Importance of scenario analysis in urban development for urban water infrastructure planning and management. Computers, Environment and Urban Systems 68:9-16.
Molinos-Senante M, Sala-Garrido R (2017). How much should customers be compensated for interruptions in the drinking water supply? Science of the Total Environment 586:642-649.
Molobela IP,Sinha P (2011). Management of water resources in South Africa: A review African Journal of Environmental Science and Technology 5(12):993-1002.
Morais DC, de Almeida AT (2007). Group decision-making for leakage management strategy of water network. Resources, Conservation and Recycling 52(2):441-459.
Musyoki AN,Gakuu C (2018). Institutional factors influencing implementation of infrastructure projects by county governments in Kenya: A case of Embu County, Kenya. International Academic Journal of Information Sciences and Project Management 3(2):446-471.
Mutikanga HE (2012). Water loss management: tools and methods for developing countries. IHE Delft Institute for Water Education.
Mwanza BG, Mbohwa C (2016). The impact of maintenance systems on water supply: a case study of a utility company. In Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management.
Nafziger M, Koo D (2015). Developing Framework for Alternative Funding Options in Water Infrastructure Projects. Journal of Building Construction and Planning Research 3(01): 27.
Nganyanyuka K, Martinez J, Wesselink A, Lungo JH, Georgiadou Y (2014). Accessing water services in Dar es Salaam: Are we counting what counts? Habitat International 44: 358-366.
Note F (2017). Financing Water Infrastructure. Water, Security and US Foreign Policy, p. 307.
Opresnik D, Taisch M (2015). The Conceptualization of Sustainability in Operations Management. Procedia CIRP 29:532-537.
Pardo-Bosch F, Aguado A (2016). Sustainability as the key to prioritize investments in public infrastructures. Environmental Impact Assessment Review 60:40-51.
Parlikad AK, Jafari M (2016). Challenges in infrastructure asset management. IFAC-PapersOnLine 49 (28):185-190.
Pietrucha-Urbanik K (2015). Failure prediction in water supply system– current issues. In: Theory and Engineering of Complex Systems and Dependability. Springer, pp. 351-358.
Pihljak LH (2014). Water pricing regimes and production of urban waterscape. UNESCO-IHE.
Pryke M, Allen J (2018). Financialising urban water infrastructure: Extracting local value, distributing value globally. Urban Studies 0042098017742288.
Rajé F (2017). Local financing for infrastructure in Zambia. University of Birmingham.
Rillo AD, Ali Z (2018). Toward an innovative approach of financing infrastructure in Asia. Journal of Infrastructure, Policy and Development 2(1):87-96.
Rodda N, Stenström T, Schmidt S, Dent M, Bux F, Hanke N, Buckley C, Fennemore C (2016). Water security in South Africa: perceptions on public expectations and municipal obligations, governance and water re-use. Water SA 42(3):456-465.
Rodriguez DJ, van den Berg C, McMahon A (2012). Investing in water infrastructure: capital, operations and maintenance.
Roelich K, Knoeri C, Steinberger JK, Varga L, Blythe PT, Butler D, Gupta R, Harrison GP, Martin C, Purnell P (2015). Towards resource-efficient and service-oriented integrated infrastructure operation. Technological Forecasting and Social Change 92:40-52.

Roibas D,Garcia-Valiñas MA, Fernandez-Llera R (2018). Measuring the Impact of Water Supply Interruptions on Household Welfare. Environmental and Resource Economics pp. 1-21.
Roushdy R, Sicvcrdiin M (2016). Improved water and child health in Egypt: impact of interrupted water supply and storage of household water on the prevalence ot diarrhoea. EMHJ-Eastern Mediterranean Health Journal 22(1):5-19.
Samir N, Kansoh R, Elbarki W, Fleifle A (2017). Pressure control for minimizing leakage in water distribution systems.Alexandria Engineering Journal 56(4):601-612.
Schlachter B, Coleman M, Anway N (2011). Key Challenges and Strategies for Local Government. Pittsburgh, PA: Institute of Politics, University of Pittsburgh.
See KF, Ma Z (2018). Does non-revenue water affect Malaysia's water services industry productivity? Utilities Policy 54:125-131.
Smetanov A, Paton EN, Maynard C, Tindale S, Fernández-Getino AP, Marqéus Pérez MJ, Bracken L, Le Bissonnais Y, Keesstra SD (2018). Stakeholders' perception of the relevance of water and sediment connectivity in water and land management. Land Degradation and Development 29(6):1833-1844.
Taylor DD, Slocum AH, Whittle AJ (2018). Analytical scaling relations to evaluate leakage and intrusion in intermittent water supply systems. PloS One 13 (5):e0196887.
Trudeau J, Aksan AM, Vásquez WF (2018). Water system unreliability and diarrhea incidence among children in Guatemala. International journal of Public Health 63(2):241-250.
Ugu District Municipality (2019). Water supply interruptions report.
Van Zyl (2014). Introduction to Operation and Maintenance of Water Distribution Systems. South Africa: Water Research Commission.
Wang K, Davies EG (2018). Municipal water planning and management with an end-use based simulation model. Environmental Modelling and Software 101:204-217.
Wang T, Liu S, Qian X, Shimizu T, Dente SM, Hashimoto S, Nakajima J (2017) . Assessment of the municipal water cycle in China. Science of The Total Environment 607:761-770.
Wei Y, Wang Z, Wang H, Yao T, Li Y (2018). Promoting inclusive water governance and forecasting the structure of water consumption based on compositional data: A case study of Beijing. Science of The Total Environment 634:407-416.
WHO/UNICEF (2014). Progress on drinking water and sanitation: 2014 Update. World Health Organization.
Xu Q, Liu R, Chen Q, Li R (2014). Review on water leakage control in distribution networks and the associated environmental benefits. Journal of Environmental Sciences 26(5):955-961.
Yazdandoost F, Izadi A (2018). An asset management approach to optimize water meter replacement. Environmental Modelling and Software 104:270-281.