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ORIGINAL ARTICLE

Performance indicators of water supply network of Goma Township in the Democratic Republic of Congo: a tripartite assessment

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Abstract
In Goma Township, the water supply system has become ineffective and insufficient against the background of an increasing population with high water demand. A study was therefore carried out to assess the water supply network of Goma Township using three performances indicators with a view to proposing possible solutions to the existing water supply challenges. The methodology involved the assessment and evaluation of the water production, the physical characteristics, and the hydraulic characteristics of the current water supply network. The research utilized secondary data comprising technical reports from review of the literature, GIS data sets, and a database of the existing network converted into an EPANET model to assess its performances. The results generally showed a low performance of the current water supply system (production capacity: 11%, hydraulic characteristic: 33%, physical characteristic: 71%) mainly related to the water demand which has outpaced the water supply capacity and several design issues. The methodology used in this study and the results obtained can be used not only for Goma Township but also by other Sub-Saharan African cities in order to solve the urban water supply crisis.

Keywords Assessment · Sub-Saharan Africa · Water supply · Network · Performance indicator · Sustainability

Introduction

Most of the Sub-Saharan African countries face inconsistent water supply in their cities, townships and municipalities. In addition to limited and /or ineffective water supply networks, the high demand for water due to high and rapid population growths in the urban setups have exacerbated the water shortage. The water supply challenges are further made serious due to lack of resources to cover the operation and the maintenance costs of the water supply networks (Arcadis 2016; Banejee and Morella 2011; Eberhard 2019). Therefore, the status of the urban water supply is often worrisome in Sub-Saharan municipalities, and its importance undervalued. This situation led the continent to miss the water and sanitation Millennium Development Goal (MDG) and will likely not be able to realize the African water vision 2025 focused on, "An Africa where there is an equitable and sustainable use and management of water resources for poverty alleviation, socio-economic development, regional cooperation, and the environment," and the Sustainable Development Goal (SDG) number 6 on "Clean water and sanitation for all" in 2030 (UNWA, 2003; Berg et al. 2017).

Moreover, many African water utilities struggle to cover and supply water to an entire township with the limited existing infrastructure of the water network system. For instance, a study by Eberhard (2019) shows that only 56% of city-dwellers in Sub-Saharan Africa had access to piped water during the year 2019. This observation represents a decrease of 12% compared to the implementation period of the Millennium Development Goals (MDG) when 68% of city-dwellers were connected to water systems (Banejee and Morella 2011). Statistics show that the water supply systems in many urban areas in Africa are unsustainable, a situation that is exacerbated by increased urban population growth rates with unprecedented water demand (Eberhard 2019).

For instance, the Democratic Republic of Congo (DRC) with the third largest urban population in Africa has

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experienced rapid population growth of more than 1 million inhabitants per year in its cities. This has aggravated the already existing serious challenges in the water supply sector (World Bank 2018). A study by Chishugi and Xu (2009) suggests that the rapid growth in the DRC is partly due to the rural exodus and the massive immigration caused by former political crises. Indeed, from 1996 to 2006, the country experienced political instabilities leading to massive movements of populations within the country. In addition, the high birth rate in the country (6.02 births per woman) has also continued to play an important role in this demographic explosion in the DRC (World Bank 2020). Thus, the urban water demands have increased, while the systems' coverage, reliability and resilience of water supply systems have decreased. According to the International Benchmarking Network (2018), only 24.79% of urban areas of the DRC were covered by water supply networks in 2014. This represents a decrease of 36% compared to 2004 statistics when 61% of the cities' areas were covered by water supply networks.

Consequently, the Goma Township, in the eastern region of the DRC, is a typical example of townships in the sub-Saharan Africa experiencing the urban water challenges in terms of both quality and quantity. With a population forecasted as 634,197 inhabitants in 2020 by the United Nations (2018), Goma Township has an unreliable water system demonstrated by repetitive and long period of water shortages (Vagheni 2019). The situation has forced many city-dwellers to use alternatives solutions such as rainwater harvesting and /or getting water directly from other water bodies located within the township (ICRC 2017). These alternative water sources have exposed the inhabitants to recurrent outbreaks of waterborne and water-related diseases such as Cholera, Ebola and Typhoid, because most of the water is untreated and therefore unsafe and unfit for human consumption (Mouangue and McCalmont 2019). Furthermore, the situation has contributed to slowing down the economic growth of the township since most of the women and children spend their productive time fetching water from long distances and spending a lot of time waiting due to the long queues (Vagheni 2019).

Therefore, the objective of this study was to assess the urban water supply network of Goma Township with three main indicators: the water production, the physical characteristics and the hydraulic characteristics (Alegre et al. 2006). For the physical characteristics, the study used sub-indicators which were the coverage, the material and the age of the pipes whereas for the hydraulic characteristics, the pressures and the velocities were considered (Hajibabaei et al. 2019). Regarding the water production, the indicator was found by comparing the offer to the demand. Finally, all the assessments were done on percentage scales (Alegre et al. 2006).

Review of the urban water supply assessments in Africa

Many scholars have assessed the performances of urban water supply networks on the continent with different approaches. For instance, Abdelbaki et al. (2014) assessed the efficiency and the performance of the drinking water supply network of Tlemcen in Algeria using a three-stage quality management approach. The results portrayed a system that suffered from an insufficient production to cover the water demand coupled to a 50% loss through leakages. In another study, Mottier (2009) worked on the distribution network of the Goma Township, in the Democratic Republic of Congo and found insufficient infrastructures, inadmissible pressures in many parts of the township, and leakages caused by poor maintenance practices of the network's equipment. Also, Izinyon and Anyata (2009) assessed the hydraulic performances of the water supply network of Sakwa, in Nigeria using WaterCAD simulations. The results showed an acceptable network but with some inadequate infrastructures. In summary, the technical assessments of scholars have generally pointed out many challenges on African water supply networks.

With respect to water policy, Carden and Armitage (2013) assessed the sustainability of nine urban networks in South Africa. The study came up with a composite index called the Sustainability Index for Integrated Urban Water Management (SIUWM) that could be used to improve the water services of the studied networks. In another study related to water policy, Mbuvi et al. (2012) also studied the urban water supply utilities on the continent with a policy approach. The assessment examined the effectiveness of several African water drinking utilities to meet the water demand of their customers. The results showed that African utilities faced more inefficiency challenges than ineffectiveness challenges. In the same line, another study by Berg et al. (2017) commissioned by the World Bank assessed the performances of African water utilities using online databases. The results confirmed the weak performances of African utilities by their inabilities to improve their performances due to lack of resources and/or extreme dependence to external funding.

At the international level, the researchers have suggested and have continued to provide different improved methods and technics to assess the performances of urban water supply networks. The studies vary from intrinsic estimations of the water supply networks characteristics which include water demand, quality, physical and hydraulic state. The methods also evaluate the effect of external conditions or threats (for instance contaminants, earthquakes, etc) to the network (Qiao et al. 2007; Sargaonkar et al. 2013; Sanjuan-Delmás et al. 2015; Seo et al. 2015). Thus, the mathematical models are mostly used in decision making by policy makers while the technical researches focus on pipe conditions and contaminants ingress in water supply systems (Sargaonkar et al. 2013).

The assessment techniques of water supply networks have considerably improved with the technological development over the last decades (Walski et al. 2003). The geographic information systems (GIS) are now integrated to hydraulic databases and models to evaluate the performances of water supply networks under variable conditions and scenarios. These advancements in technology allow utilities and decision makers to adopt more accurate strategies in the updates and the investments of networks. However, a considerable increase in the number and the quality of assessment studies regarding Sub-Saharan water supply networks is necessary to improve the water and sanitation situation of Africa.

Materials and method

Study area

Geographically situated within latitude 1°35′ 15″–1°42′15″ S and longitude 29° 06′ 45″–29 15′ 45″ E, Goma is a township located in the Eastern part of the Democratic Republic of Congo (DRC) as given in Fig. 1. The township borders to its East the town of Gisenyi in the Republic of Rwanda, to its West, the National Park of Virunga in the territory of Masisi, to its North, the territory of Nyiragongo on the versant of the 2 active volcanos (Nyiragongo and Nyamuragira), and to its South, it borders with the Kivu lake which forms its natural boundary with the Province of South Kivu. In addition, Goma is the capital city of the Northern Kivu Province. The distance of Goma from Kinshasa, the country's capital city is approximatively 1500 km. Besides that, the Goma Township is administratively divided into two communes and 18 quarters as given in Fig. 1. Its hydrography is shaped by lakes and rivers among which the Kivu lake is the most important with a water capacity of 500 km^3 (Thiery et al. 2014). According to CGIAR (2020), the elevations vary from 1460 to 1650 m above sea level. Due to its location in

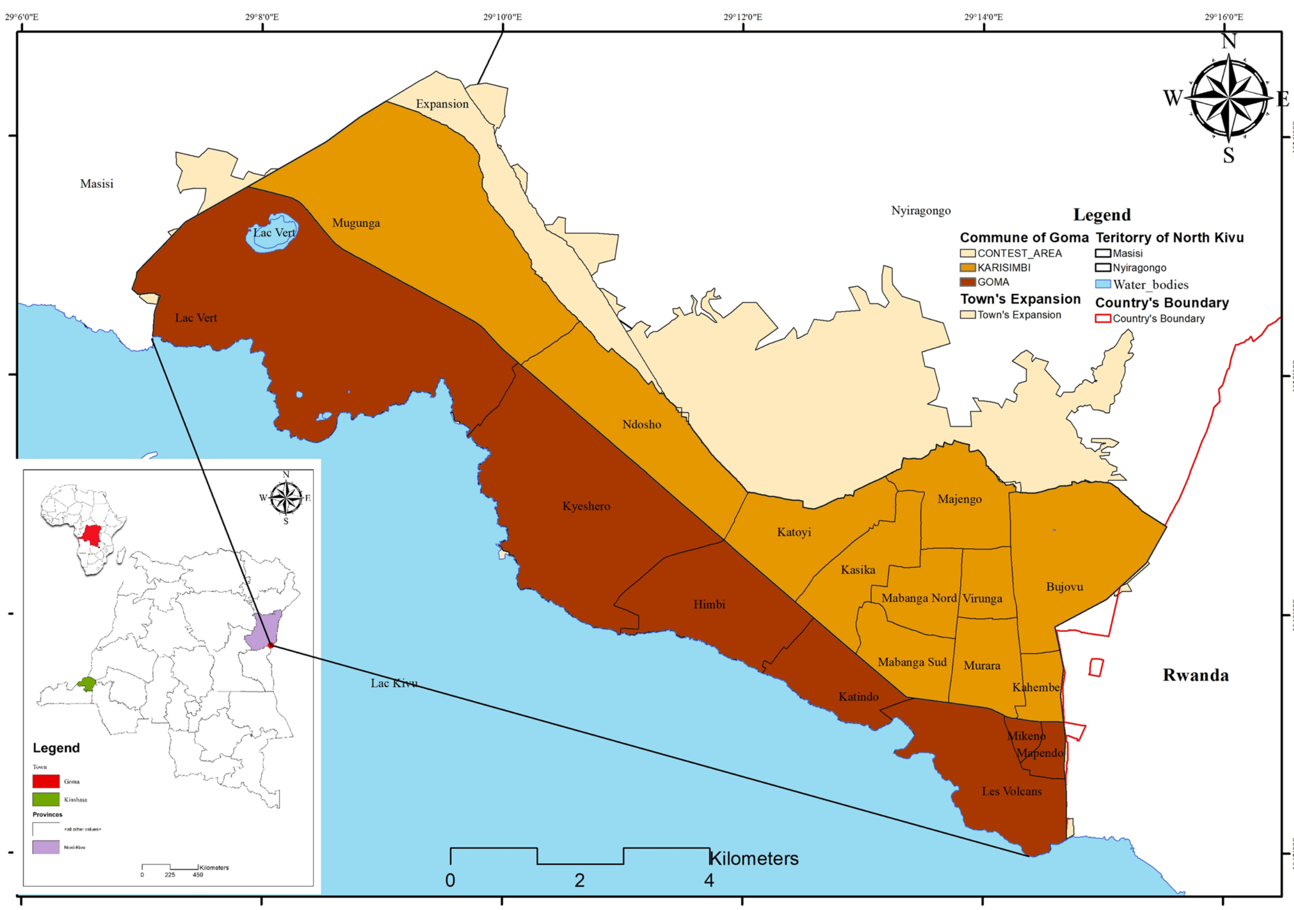


Fig. 1 Goma Township

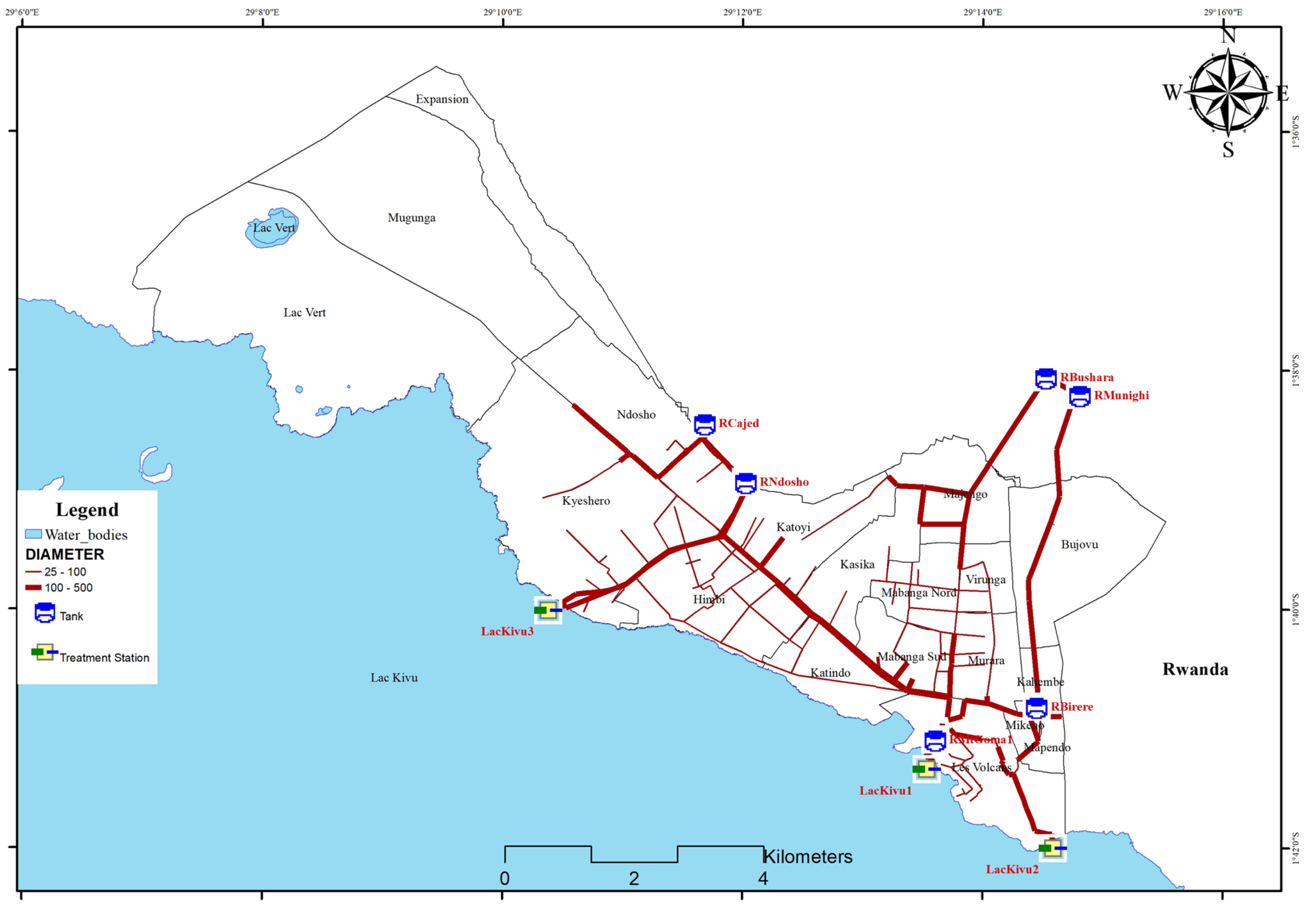


Fig. 2 Water supply network of the Goma Township

the volcanic region of the East African Rift Valley, its soil is magmatic. Goma Township's climate is tropical with an annual average temperature and rainfall of 22 °C and 981 mm (NOAA 2020)

Existing network

As given in Fig. 2, the water system of Goma Township comprises three water treatment plants (Lake Kivu 1, 2 & 3) and six reservoirs (Cajed, Ndosho, Bushara, Munighi, Birere and Goma1) which are interconnected by a pipe network. The pipes are fabricated using different materials, and their diameters vary from 25 to 500 mm. Besides that, the network functions under the principle of the balancing tank system, a combined system which works partially with pumps and partially with gravity. As presented in Fig. 2, the Environment Protection Agency Network (EPANET) (Rossman 2000) model obtained and calibrated from the Network Survey Manager (NSM) (Wismer 2014) data collected at ICRC/Whathab team of Goma demonstrated that the pumping stations are in service for 20 h per day (2–22h), and they simultaneously supply water to the consumers while filling the six reservoirs. Therefore, the electrical energy is crucial for the network to function properly for 20 h per day. For the remaining 4 h, the volume of water stored in the six tanks is used to supply the costumers where water is distributed through a gravity system.

Data collection

The necessary data for this study consisted of a population file containing the evolution and projection of the Goma's population from 1950 to 2035. It was obtained from the United Nations (2018), Department of Economic and Social Affairs, Population Division which was published under the title: "World Urbanization Prospects: The 2018 Revision, Online Edition." The file was used in the estimation of the water demand. Secondly, the report "Réseau de distribution d'eau potable de la ville de Goma'' commissioned by the International Committee of Red Cross (ICRC) and published by the Swiss construction company Perreten and Milleret (Mottier 2009). The report contained the descriptions of the network's physical characteristics which were used in the assessment of physical characteristics. Thirdly, the Network

Survey Manager (NSM) database of the Goma's network was obtained from the ICRC/WatHab team of Goma. The network database which consists of: 345 Junctions, three water sources, six tanks, eight pumps, 373 pipes, nine patterns and ten curves was used to create the EPANET model of the Goma water supply network. The model was then used in the assessment of the water supply system's hydraulic characteristics.

Methods

The evaluation of the water supply network in the Goma Township was carried out using a tripartite assessment process where the performance indicators of three principal characteristics on a percentage scale were determined. The study adopted the ranking scale used by Alegre et al. (2006) as: 0–50 % (Low), 50–75% (Medium) and 75–100% (Good).

During the study, production capacity of the existing infrastructures was assessed by determining the performance indicator using Eq. (1) adopted from Abu Zahra (2001) given as:

$$I_{\text{Production}} = \frac{\sum Q_{\text{Existing acilities}}}{Q_{\text{Demand}}} \times 100 \tag{1}$$

Where $I_{\text{Production}}$ = Performance indicator related to the production capacity of the system (%)$Q_{\text{existing Facilities}}$ = Production capacity of the existing facilities (m^3/d)Q_{Demand} = Estimated water demand in the township for the year 2020 obtained using Eq. (2) adopted from Dessu et al. (2014), Mottier (2009) and Udmale et al. (2016)

$$Q_{\text{Demand}} = P_{\text{Est}} \times W_{\text{al}} \times F_N \times W_l \times F_s \tag{2}$$

Where P_{Est} = Estimated population (634 197 inhabitants) W_{al} = Water allocation (150l/c/d) F_N = Factor for non-domestic consumption (1.17) W_l = Water losses factor (1.25) F_s = Seasonal variation factor (1.1). The physical characteristics were assessed regarding the coverage, the age and the type of materials used. The coverage was evaluated by establishing the percentage of the township covered by the network layout using Eq. (3) adopted from Alegre et al. (2006)

$$\text{Coverage}(\%) = \frac{\text{Area covered by the network}}{\text{Total Area of the township}} \times 100 \tag{3}$$

All the pipes with more than 30 years of service needed a replacement; thus, the study evaluated the pipes percentage in service before 1990. For the other pipes, the range of 20–30 years was considered as Medium and less than 20 years as Good (Rezaei et al. 2015).

For the materials, the volcanic nature of the Goma's soil (magmatic rock) imposes the ductile iron (ductile cast iron) as the adequate pipe material; therefore, the percentage of the network in this material was computed as Good (Dupont 1979; Mottier 2009). All other pipes containing steel in their fabrication had a medium performance and the rest pipe materials were classified as low.

The hydraulic characteristics were assessed using EPANET (Rossman 2000). As given in Fig. 3, the EPANET model of the Goma's network helped to determine the pressures at each of the 345 nodes and the velocities in each of the 373 pipes for a 24-h exercise using the data provided in the NSM database. Therefore, the two hydraulic characteristics were assessed at 5:00 pm, the time corresponding to the highest value of the demand pattern, and at 1: 00 am when all the pumps in the network were off. The favorable working pressure head range was found out to be between 6 and 40 m of water column. Moreover, from 40 to 60 m were considered as medium and any other pressure was considered as low (Dupont 1979; Trifunovic 2006). Abdelbaki and Touaibia (2014) suggested that an optimum velocity range of between 0.5 and 1.5 m/s to be the optimum velocity. However, values from 1.5 to 2 m/s were considered as medium.

The tripartite assessment was obtained by reporting the results on a radar figure because the characteristics had the same scale (percentage) for the assessment.

Results and discussion

Water production

As suggested regarding the water supply situation of Sub-Saharan African cities, the water demand of the Goma Township has also outpaced the production capacity of its water supply system. The production capacity of the three water treatment plants reported in the network database was 17,214 m^3/d. However, during 2020, the water demand of the Goma Township was estimated as 153,353 m^3/d. Therefore, the existing facilities supplied only 11.2% of the township's water demand. This is an indicator of a network that is not able to meet the required water demand for the township (Sapkota et al. 2016).

Physical characteristics

Coverage

As given in Fig. 2, it is observed that the water supply network of Goma does not cover the entire township. The coverage percentage computed was 57.6% (33.6 km^2) with the assumption that the settlement of Lac vert, Mugunga and one third of Ndosho as well as Kyeshero were not covered. The assumption was made since the information from the database did not show availability of any pipes in these areas. Therefore, the system's performance based on the

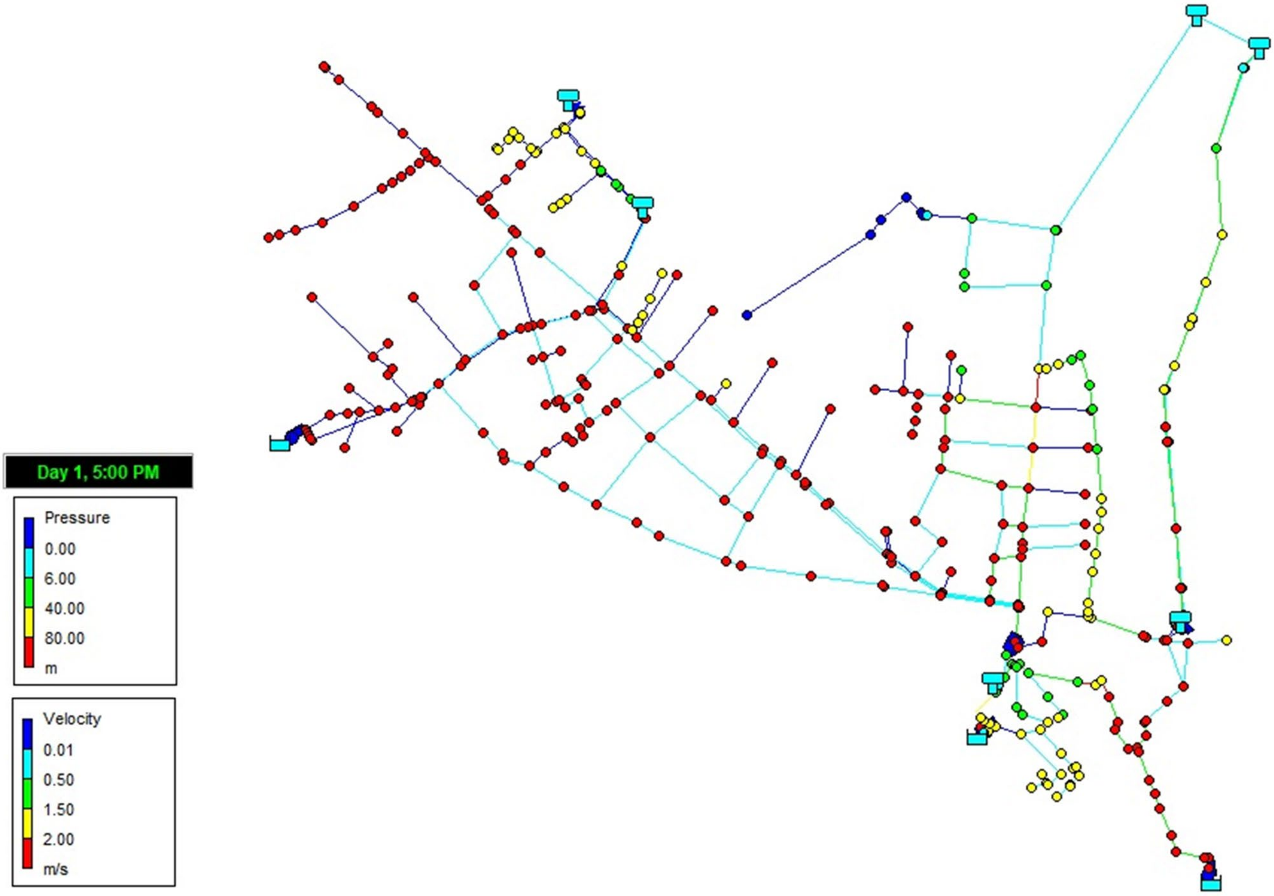
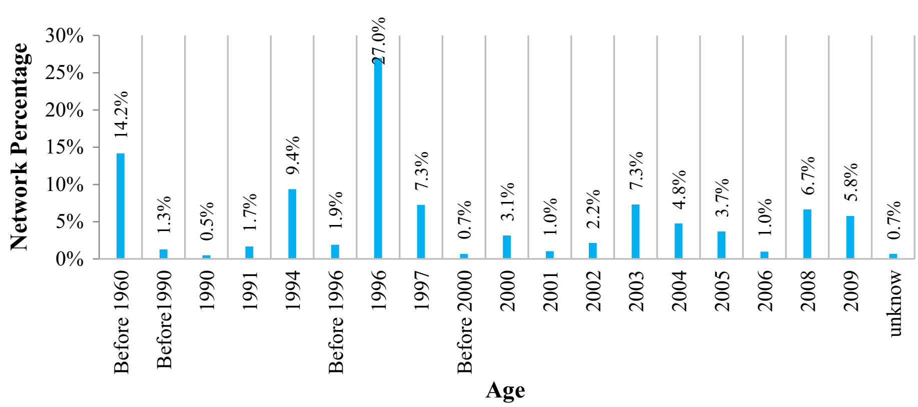


Fig. 3 EPANET simulation of the Goma's water supply network

Fig. 4 Pipe ages of the Goma's water supply network



coverage indicator was medium with a 57.6%. This percentage was found admissible even though, several extensions of the water supply network are needed in the township as it was also proposed by Mottier (2009).

Pipe ages

Figures 4 and 5 present the ages of the pipes network where the results show that the network was built before 1960, with a major update in 1996. However, only a cumulus of 14.8% of the pipes needed a replacement regardless of their materials because they have been in service for more than 30 years

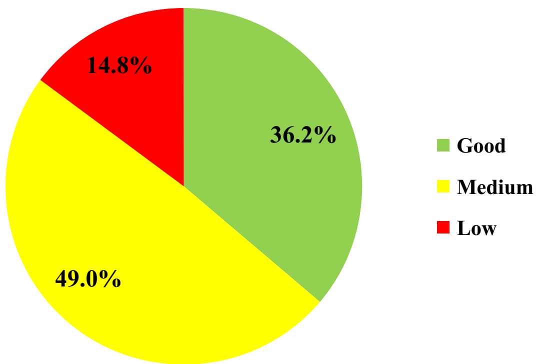


Fig. 5 Assessment of pipe ages

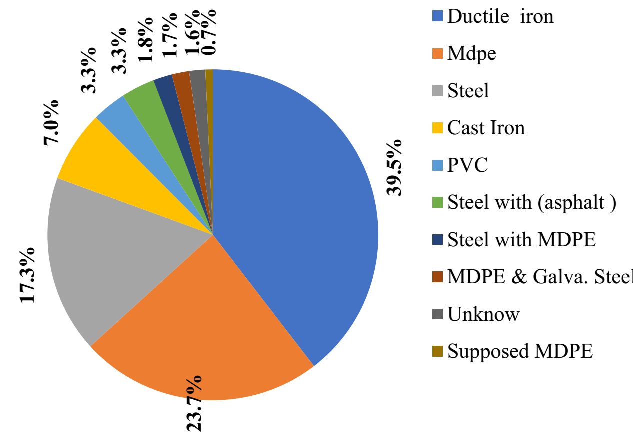


Fig. 6 Pipes materials of the Goma Township's water supply network

since the last major update was done in 1996. Therefore, the performance indicator regarding the age of the network was medium. The results show that 75.6 % of the pipes network had an acceptable age as given in Fig. 5.

Pipes' materials

The existing water supply network in Goma had 73 593 m of length; however, as given in Fig. 6, only 39.55% of the network was ductile iron (ductile cast iron), the adequate material for the magmatic soil of Goma. From the results, it can also be observed that 70.6% of the pipes were steel. Although the steel pipes could be used, there is need for regular assessment of their viability to ensure that their capacities are not compromised through corrosion. Although 70.6% of the pipes were functional in the Goma Township, the remaining 29.4% of pipes presented a threat for the sustainability of the current network. Therefore, the performance indicator regarding the pipe materials was medium as given in Fig. 7 and was acceptable according to Mottier (2009).

The network presented medium physical characteristics. The coverage, the age and the materials were generally acceptable, even though they have shown possibilities of amelioration. By the assignment of the same weights to the three components, the general performance of the physical characteristics computed was 71%, suggesting the assessment of hydraulic characteristics to evaluate the design of the network.

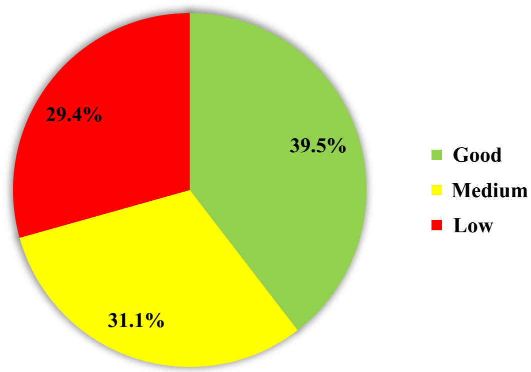


Fig. 7 Assessment of pipe materials

Hydraulic characteristics

Pressures

The EPANET model revealed an important difference between the pressure values during the two working phases of the network as given in Fig. 8. The results show that at 5:00 pm when all the pumps were on and the daily water demand was at its highest value, 72.6% of the nodes presented either more than 60 m of pressures or low pressures. However, at 1:00 am when all the pumps were off and the demand at its lowest value, meaning that the network was working only by gravity (Fig. 8), 71.3% of the nodes presented acceptable values. Therefore, the performance indicator obtained for the pressures during the two working phases of the network was a low performance in general because 50.7% of the nodes had inadmissible values compared to the standards as given in Fig. 9. The results from this study are in agreement with those obtained by Hajibabaei et al. (2019).

Velocities

The two working phases of the network simulated on the EPANET model performed poorly regarding the velocity indicator. As given in Fig. 10, it can be observed that at 5:00 pm when the production and the demand were maximum, 80.6% of the velocities had a value either more than 2m/s or less than 0.5m/s which according to the standard

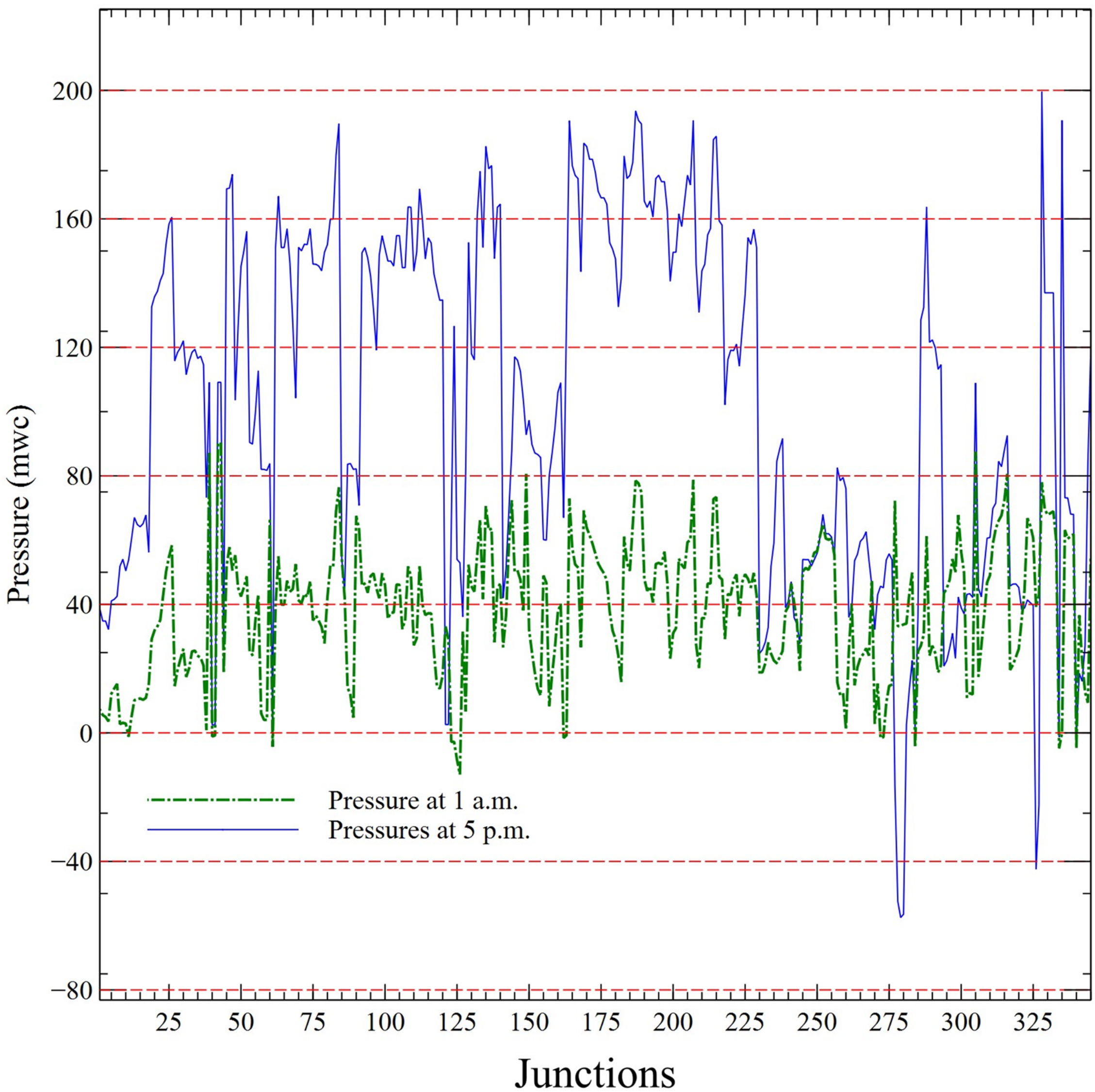


Fig. 8 Pressure fluctuations in the Goma's water supply network

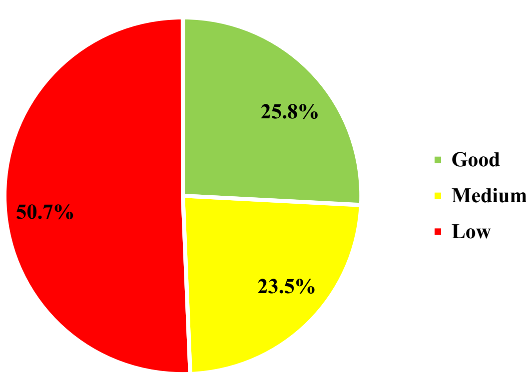


Fig. 9 Assessment of pressures

were inadmissible (Abdelbaki et al. 2014). Also, at 1:00 am, the velocities were generally low with 84.8% links presenting inadmissible values. Therefore, the velocity indicator obtained for the two working phases was low as given in Fig. 11 because 82.7% of pipes presented inadmissible values (Hajibabaei et al. 2019).

The results show that network performed poorly regarding the hydraulic characteristics. The pressures and the velocities have shown low performances leading to an overall hydraulic characteristic of 33%. This low value highlighted some issues in the network design, a situation principally associated with the shift between the water supply by pumps and by gravity.

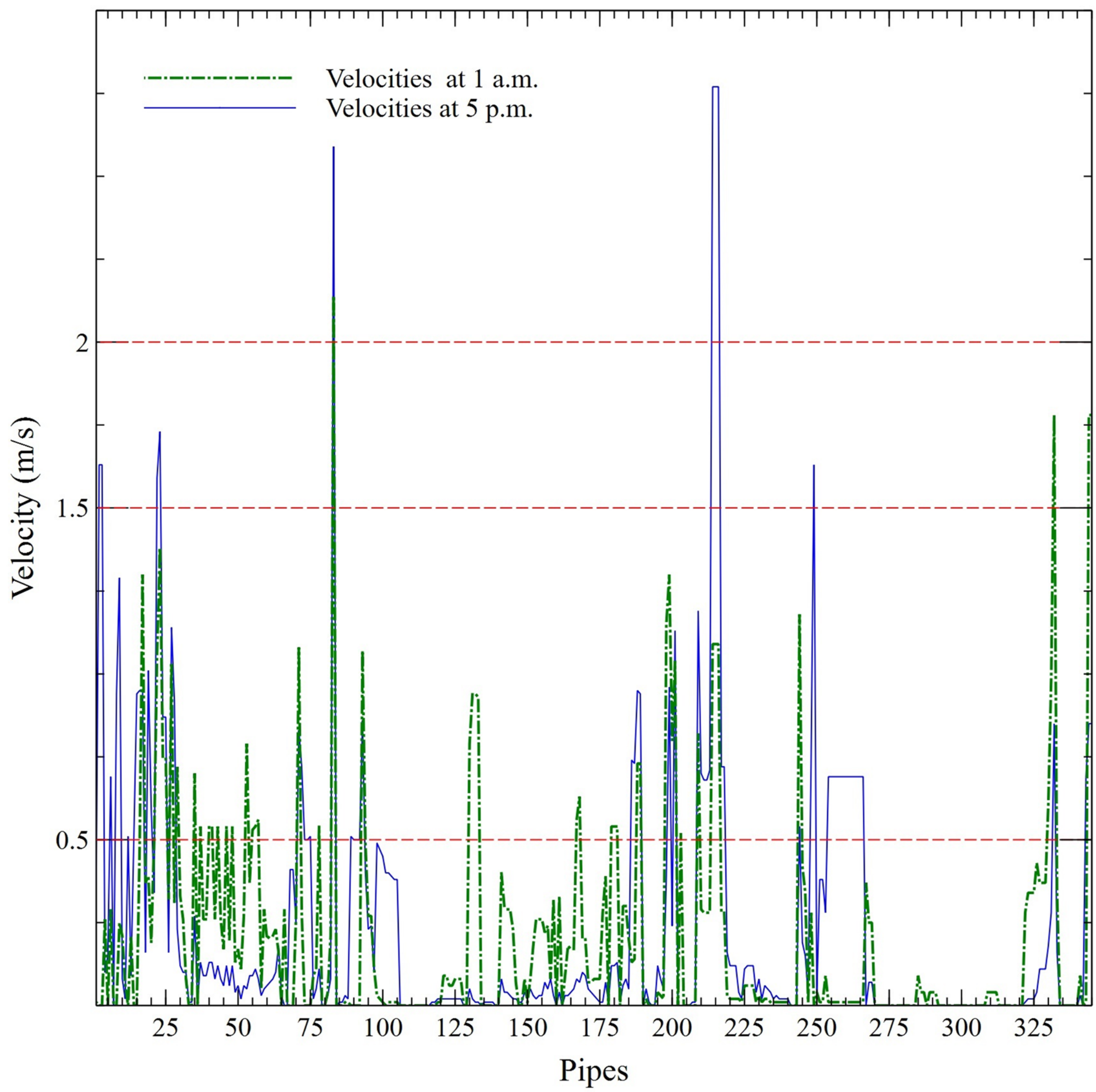


Fig. 10 Velocity fluctuations in the Goma's water supply network

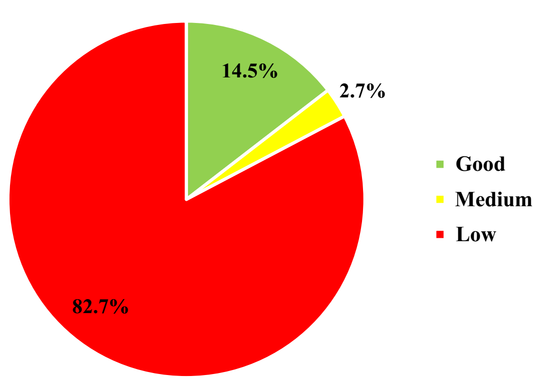


Fig. 11 Assessment of velocities

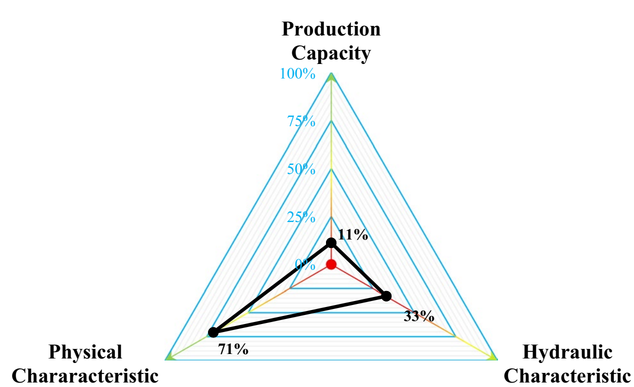


Fig. 12 Tripartite assessment of the water supply network of Goma Township

Tripartite assessment

As presented in Fig. 12, the tripartite assessment of the water supply system of the Goma Township has demonstrated a network with two major problems: the production capacity and hydraulic characteristics. With the same scale used for the production capacity, the physical and the hydraulic characteristics, results presented in Fig. 12 portray a general poor performance of the current water supply network. Although the performances related to the physical characteristics were generally acceptable, the water demand was found out to be ten times more than the capacity of the existing facilities suggesting the extension of the network as a priority. The results also show that the design of the present system did not comply with the standard of hydraulic characteristics (pressures and velocities). There is therefore an urgent need to correct the hydraulic design of the current network to meet acceptable standards. These two challenges present considerable threats for the sustainability of the water supply in the Goma Township and the provision of potable water for domestic use and for basic sanitation requirements to all its city-dwellers. Finally, the case study has confirmed the poor water supply situation of many Sub-Saharan African cities where similar experiences could be extended in order to scientifically explain the reasons why most African countries are likely to miss their water supply goals as provided for in the SDGs, 2030.

Conclusion

The study's methodology provides scientific results to understand the water supply situation in the Goma Township and could be generalized to other African cities. It gives a visual explanation of the state of a network which allows planners and decision makers to identify the specific characteristics on which they should focus their attention for rehabilitations and future investments. Such a diagnostic method if adopted could considerably reduce the cost of investments in Sub-Saharan African water supply networks while maximizing their effectiveness. Also, the results from this study could serve to benchmark the African urban water supply networks against each other if used in a continental database. This would help scientist to improve the understanding of the water supply situation on the continent, especially if more detailed characteristics related to water quality, energy, etc. are integrated into the method for multipartite assessments.

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Declarations

Conflict of interest The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper. On behalf of all authors, the corresponding author states that there is no conflict of interest.

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