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ORIGINAL

Integral optimization of the Quebrada La Honda water supply system: social and financial impacts in Villavicencio, Meta

Optimización integral del sistema de acueducto en Quebrada La Honda: impactos sociales y financieros en Villavicencio, Meta

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ABSTRACT

Introduction: access to drinking water is essential for human development and is considered a universal right. In Colombia, regulations establish the characteristics and standards to ensure its quality as a domiciliary public service, including physicochemical properties of water and design criteria for hydraulic infrastructures.
Objective: to evaluate the aqueduct system in the Quebrada La Honda sector in Villavicencio, Meta, to propose solutions to improve its infrastructure.
Method: an exhaustive review of technical documents, previous studies and regulations, as well as surveys and interviews with the local community were carried out to evaluate the social impact of the collapse of the aqueduct system.
Development: the study identified significant problems in the adduction system from Quebrada La Honda to the La Esmeralda Drinking Water Treatment Plant, including the undersizing of the intake and the vulnerability of the infrastructure to natural phenomena. Service interruptions negatively affect the local quality of life.
Conclusions: it is proposed to redesign the intake and use ductile steel pipes to improve the durability and efficiency of the system, also recommending the implementation of a continuous surveillance and monitoring system to ensure long-term sustainability.

Keywords: Drinking Water; Infrastructure; Public Service; Aqueduct System.

RESUMEN

Introducción: el acceso al agua potable es esencial para el desarrollo humano y se considera un derecho universal. En Colombia, la normativa establece las características y estándares para asegurar su calidad como servicio público domiciliario, abarcando propiedades fisicoquímicas del agua y criterios de diseño de infraestructuras hidráulicas.
Objetivo: evaluar el sistema de acueducto en el sector Quebrada La Honda en Villavicencio, Meta, a fin de proponer soluciones para mejorar su infraestructura.
Método: se realizó una revisión exhaustiva de documentos técnicos, estudios previos y normativas, así como encuestas y entrevistas con la comunidad local para evaluar el impacto social del colapso del sistema de acueducto.
Desarrollo: el estudio identificó problemas significativos en el sistema de aducción desde Quebrada La Honda hasta la Planta de Tratamiento de Agua Potable La Esmeralda, incluyendo la subdimensión de la bocatoma y la vulnerabilidad de la infraestructura ante fenómenos naturales. Las interrupciones en el servicio afectan negativamente la calidad de vida local.

Conclusiones: se propone rediseñar la bocatoma y utilizar tuberías de acero dúctil para mejorar la durabilidad y eficiencia del sistema, recomendando también la implementación de un sistema continuo de vigilancia y monitoreo para garantizar la sostenibilidad a largo plazo.

Palabras clave: Agua Potable; Infraestructura; Servicio Público; Sistema de Acueducto.

INTRODUCTION

Drinking water is a vital element for human development. Therefore, access to this element has been classified as a universal human right whose distribution must be equitable to promote respect for human dignity.[1] Similarly, drinking water must be free of any substance, pathogen, or microorganism that compromises public health; therefore, different normative references have emerged on the physicochemical and bacteriological characteristics that water intended for human consumption must have.[2] Such is the case of Colombia, where Resolution 2115 of 2007 was established, which dictates the different characteristics, instruments, and frequencies of control and surveillance that water must have to ensure its quality.

Along the same lines, it is Law 142 of 1994 that treats drinking water as a public utility based on the integral use and management of water resources for the development of human beings.[3] Thus, in order to guarantee the provision of quality service to the community, Resolution 0330 of 2017 dictates the technical requirements that must be met in the planning, design, construction, operation, maintenance, and restoration of the infrastructure involved in the management of residential, public services of water, sewerage and sanitation.[4] However, despite strict regulations, it is common to see that the community suffers from service disruptions, whether due to the quality of treatment, the supply network, or the distribution network.

In many regions of Colombia, the aqueduct system faces significant challenges that lead to its collapse and deterioration. One of these challenges is the capacity of the aqueducts to cope with natural phenomena such as mass movement or heavy rainfall;[5] there are also problems of aging infrastructure, poor resource management, and lack of investment in maintenance and modernization.[6] These factors, combined with increased demand due to population growth and climate change, can lead to a progressive deterioration of the service, which has social and financial repercussions for the affected community. Thus, when an aqueduct system collapses, the consequences are immediate and severe: interruptions in the water supply, an increase in water-related diseases, and a general deterioration in the quality of life.[7]

From a more specific context, the Quebrada la Honda sector in the city of Villavicencio, Meta, has witnessed the devastating effects of the collapse of its aqueduct system.[8] The lack of a constant and reliable water supply has generated problems affecting residents. The public administration must seek costly alternatives to obtain water, such as the partial supply from deep wells,[9] which increases the financial burden. In addition, the water service interruption negatively impacts local economic activities, from commerce to agriculture, exacerbating the community's financial situation.

The present study aims to evaluate the aqueduct system in the Quebrada La Honda sector, Villavicencio, Meta, highlighting the urgent need for comprehensive solutions that address both the improvement and expansion of the infrastructure, taking into account the social and financial impacts associated with the collapse of the aqueduct in the sector. Through this research, it is hoped to provide a solid basis for decision-making and the implementation of effective strategies that mitigate the aqueduct system's susceptibility to collapse and promote the well-being of the Villavicencio community.

METHOD

Case study

The case study focused on the aqueduct system in the Quebrada La Honda sector in Villavicencio, Meta, which corresponded to the adduction system that ran from the intake to the La Esmeralda drinking water treatment plant, which supplies drinking water to the city of Villavicencio. This area was selected due to its recurring problems with the drinking water supply, which had significantly affected the local community.

Information gathering

This consisted of an exhaustive review of relevant documents and data on the aqueduct system. Technical reports, previous studies, current regulations, and other pertinent documentation were collected to represent the problem accurately. Information on the problem was also sought from academic databases, government reports, and specialized publications. In this way, the information gathered allowed the construction of a solid knowledge base on the current state of the aqueduct system and the factors that contributed to its collapse. The criteria for document selection included relevance, timeliness, and credibility of the sources.

Social impact study

This consisted of evaluating how the state of the infrastructure affected the community. Structured surveys and interviews were carried out with the community to evaluate how the deficiencies in the aqueduct infrastructure impacted their daily life, health, and general well-being.

Proposals for improvement

Based on the technical diagnosis and the social impact study results, an improvement proposal was developed to optimize the aqueduct system.

RESULTS

The Villavicencio Aqueduct and Sewerage Company[10] provides public drinking water services in Villavicencio. This entity uses the drainage network that originates in the Chingaza Moor and flows into the lotic system of Quebrada La Honda. Currently, the city of Villavicencio is supplied by six surface water sources: Quebrada La Honda, Río Guatiquía, Caño Maizaro, Caño Buque, Caño Blanco and Caño Grande; and 16 groundwater sources of which only four are in operation: Bosques de Abajam, Samán de la Rivera, Darién and Charrascal. These sources have five adduction systems to three Drinking Water Treatment Plants (PTAP) that supply around 86 % of the city's inhabitants. The following table shows the general characteristics of the adduction systems.

N°	Sistema de aducción	Diámetro (Pulgadas)	Longitud (Metros)
1	Quebrada la Honda – La Esmeralda	33 AP	15.737
2	Caño Buque – Fuentes Altas	8 PVC	800
3	Caño Maizaro – Fuentes Altas	Canal Abierto	100
4	Estación Bavaria – La Esmeralda	24 AP	1.600
5	Estación Puente Abadía – La Esmeralda	24 AP	9.801

Figure 1. Water Supply Systems in Villavicencio

The area of interest is oriented towards the 15,7 km-long adduction system from Quebrada La Honda to the La Esmeralda drinking water treatment plant. This route passes through a topographically broken area susceptible to landslides, mass movements, and erosion. The intake is located 15 km north of the town center. It is the primary supply source, providing a flow rate of 1600 L/s, representing 75 % of the water supplied to the community for consumption.[11]

According to the information published on the EAAV's digital platform, the adduction network consists of a water intake and a 33" diameter extruded aluminum pipe, a material characterized by its ability to direct liquid fluids at high pressures. According to Rocha[12], a water intake is a hydraulic structure built on a river or canal to extract part of the flow from the source; the extracted water is conducted through a system of pipes to a treatment system to make it drinkable, that is, to a DWTP.

However, water intakes, as catchment units, are exposed to special problems that directly influence their design, such as the instability of river discharges, information on hydrometeorological phenomena in the area, the transport of solids and sedimentable material by the source and the periodic occurrence of natural phenomena such as ENSO, i.e., Niño and Niña.[13]

In line with the above, the intake of the adduction system in the Quebrada La Honda sector has an irregular hydraulic capacity for water resource management. This irregularity becomes even more noticeable in the rainy seasons, as the infrastructure collapses due to the increase in water volume caused by the rainwater flowing into the source. The following figure shows a photograph of the contrast in the hydraulic capacity of the water intake in summer conditions and conditions of collapse.

Source: PDM[14]

Figure 2. Behavior of the Intake Structure

Note: the image on the left shows the Bocatoma in summer; the image on the right shows the Bocatoma in the rainy season.

Figure 1 allows us to infer that many factors, such as the increase in the volume of water due to rainwater runoff, were not considered in the design, which suggests the subdimension of infrastructure. This oversight could have been avoided if an exhaustive study had been carried out on the behavior of the stream and the drainage network belonging to the hydrographic basin. An example of the relevance of this diagnostic study is represented by Mosquera[15], who uses the methodology to determine the vulnerability of aqueduct supply sources proposed by the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM). The following table shows the variables and indicators that every vulnerability study should consider in the design phase of catchment systems.

Variables asociadas a Caudales Máximos	Variables asociadas a Caudales Mínimos	Indicadores
Morfometría de la cuenca	Hidro climatología – Curvas IDF de caudales	Índice de retención y regulación hidráulica (IRH)
Coeficiente de compacidad	Volumen bajo la curva de duración de caudales	Índice de uso del agua (IUA)
Densidad de drenaje	Volumen bajo la línea de caudales medios	Índice de vulnerabilidad hídrica (IVH)
Área de drenaje	Cantidad de agua demanda por la cuenca	Índice morfométrico de torrencialidad (IFM)
Pendiente media de la cuenca		Índice de variabilidad (IV)
Índice de torrencialidad		Índice de vulnerabilidad ante eventos torrenciales (IVET)

Source: Mosquera[15]

Figure 3. Considerable variables and indicators in determining the vulnerability of supply sources

However, in social terms, the effects of the system's collapse have been evidenced by the periodic suspension of the city's drinking water service. Since the infrastructure has been compromised mainly by torrential floods, the pipes have cracked, fragmented, and even split. An example is what happened in March of this year when there were service cuts in eight city sectors from six in the morning. This was due to infrastructure problems that required intervention in the adduction system from the Quebrada La Honda intake to the La Esmeralda drinking water treatment plant, as restoration and maintenance work had to be carried out on the system.

These service cuts caused the administration to grant a partial supply through the Bavaria pumping station during the period of the public service interruption. This presents an overload in the aqueduct system of the Bavaria station since supplying the activities of the Quebrada La Honda sector, access to the service of the primary beneficiaries of this station is compromised. In this case, there is endless news about constant interruptions in the drinking water service due to collapses in the infrastructure of the adduction system in Quebrada La Honda, as shown in the following figure.

Source: Villavo10[16]

Figure 4. Repairs to the adduction system in Quebrada la Honda

Furthermore, Resolution 082 of 2009 establishes the adoption of forms for sanitary inspection of water supply systems for human consumption.[17] Within these forms is the Risk Index for the Supply of Water for Human Consumption (IRABA), which includes the Continuity Index (CI), which corresponds to the evaluation of the quality of the drinking water service provision in terms of the hours per day that the community has access to it. Likewise, resolution 2115 of 2007 establishes that the minimum number of service hours is 18.[18] The following table shows the method of calculation of the CI and its scoring ranges for the calculation of the IRABA.

Table 1. Variables and indicators considered in determining the vulnerability of supply sources

Continuity of Service	Quality of Service	Score
0 - 10 HOURS/DAY	Insufficient	0
10,1 - 18 HOURS/DAY	Unsatisfactory	10
18,1 - 23 HOURS/DAY	Sufficient	15
23,1 - 24 HOURS/DAY	Continuous	20

Note: Ministry of the Environment, Housing and Territorial Development[18]

Therefore, although the administration tries to solve the interruptions with partial supplies, the quality of the service could not be defined as optimal since the quality of the service according to the community is not the best since there are interruptions in access for up to whole days, which violates the provisions of resolution 082 of 2009.

Likewise, according to the National Planning Department, the National Urban Development Directorate, and the Observatory of the City System, the urban population agglomeration ranks 8th. By 2050, the metropolitan area will be inhabited by around 840 000 inhabitants, representing an annual growth of 1,6 %, an increase of approximately 350 000 between 2017 and 2050. The following graph shows the above.

Población Total				Población urbana			
2005	2017	2035	2050	2005	2017	2035	2050
390.506	516.667	705.937	840.387	363.139	500.123	696.754	834.168
Porcentaje de población urbana				93%	96,80%	98,70%	99%

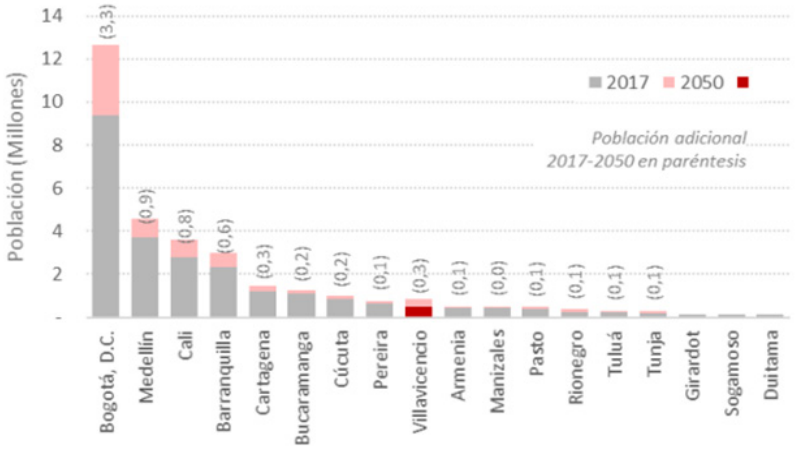

Figure 5. Population projection 2005 - 2050 for the Villavicencio urban area
Source: National Planning Department et al.[19]

Impacto	Descripción
Interrupción en el suministro de agua	Los colapsos afectan la continuidad del servicio de agua potable en la ciudad. Cuando la línea de aducción se daña, se interrumpe el flujo de agua hacia la PTAP, dejando a los habitantes sin acceso al vital recurso.
Vulnerabilidad ante emergencias	Durante la temporada de lluvias, la infraestructura de aducción es más susceptible a daños. Esto deja a la comunidad expuesta a situaciones de emergencia, especialmente cuando las lluvias aumentan los caudales de ríos y caños.
Necesidad de modernización y mantenimiento	La PTAP La Esmeralda, construida hace 42 años, está siendo modernizada para aumentar su capacidad de tratamiento. Esto es crucial para garantizar un abastecimiento adecuado de agua potable a la ciudad, incluso en condiciones climáticas adversas.
Inversión en infraestructura	Los proyectos de modernización de la PTAP y la construcción de una nueva bocatoma requieren inversiones significativas. Estos esfuerzos buscan mejorar la calidad y confiabilidad del suministro de agua para los habitantes de Villavicencio

Figure 6. Main Social Impacts Evidenced

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In summary, the following table shows the main evident social impacts on the community due to the collapse in the adduction system from the Quebrada La Honda intake to the La Esmeralda drinking water treatment plant.

According to the table, the collapses in the adduction system have generated concerns about water security and the need to strengthen the infrastructure to face climate challenges and guarantee continuous access to drinking water in the city.

Optimization Proposal

Based on the above information, the main proposal for improvement to optimize the adduction system in the Quebrada La Honda sector is to redesign the intake. Currently, the entire network faces significant financial losses due to the numerous restoration processes necessary due to its undersized and low hydraulic capacity to manage the volumes of water needed to supply the population. It is recommended that this redesign be thorough and consider all the variables previously described in figure 3 and the different methodologies established by national policies that dictate the design criteria for proper intake functioning. Although this measure represents a high public investment cost initially, it will result in notable savings in the long term since the financial resources allocated to constant repairs and restorations will no longer be necessary, and the maintenance cost will also be reduced.

However, as the PTAP has already completed its design period (25 years) it is proposed to modify the PTAP grit chamber by adding two radial gates whose dimensions should be proportional to the chambers' widths. This aims to increase the inlet area of the grit chamber and regulate the speed of the flow being treated.

In the same vein, in the design of the pipe, it must be taken into account that it must be made of a more resistant material than extruded aluminum, such as ductile steel. The latter offers excellent durability and resistance to internal and external pressure,[20] minimizing the risk of failures and leaks. In addition, ductile steel has an excellent capacity to withstand impacts and vibrations, and its flexibility allows it to better adapt to ground conditions. Using ductile steel will guarantee a longer lifespan for the pipeline system and be corrosion-resistant.[21] However, it will also significantly reduce maintenance costs and service interruptions,[22] providing a more efficient and sustainable long-term solution for the water supply system in the Quebrada La Honda sector.[23]

CONCLUSIONS

Urban growth and the lack of adequate infrastructure investment have led to significant problems with water loss, supply interruptions, and distribution failures in the aqueduct system. The aging pipe network and treatment plants with limited capacity, in addition to their difficult access and location, indicate a system that requires urgent modernization.

The proposed improvement to the aqueduct system in the Quebrada La Honda sector of Villavicencio focuses on redesigning the intake and modernizing the existing infrastructure to address current deficiencies. A thorough redesign of the intake is recommended, taking into account all the hydraulic variables and methodologies established by national policies and adding radial gates at the La Esmeralda drinking water treatment plant to increase its treatment capacity. In addition, it is suggested that the aluminum pipes be replaced with ductile steel, a stronger and more durable material, to minimize the risk of failure and reduce maintenance costs. Although requiring a significant initial investment, these measures will guarantee a more efficient and sustainable water supply for the Villavicencio community in the long term.

This study highlights the urgent need for investment in infrastructure to ensure a reliable and safe drinking water supply for the entire Villavicencio community. It underlines the importance of adopting sustainable water management practices and fostering stakeholder collaboration and coordination. Likewise, the community's active participation in decision-making and project implementation is emphasized. In addition, it is recommended that a continuous surveillance and monitoring system be established to guarantee the long-term sustainability of the improvements implemented.

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FINANCING

None.

CONFLICT OF INTEREST

Authors declare that there is no conflict of interest.

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