

Raw water challenges: difficulties and alternatives for municipal treatment

Retos de las aguas crudas: dificultades y alternativas para el tratamiento municipal

Desafios da água bruta: dificuldades e alternativas para o tratamento municipal

Andrea Hernández Cortes¹
Jorge Enrique Saby Beltrán²

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¹ Civil Engineering student and member of the SIGRON Research Group, Universidad Francisco José de Caldas, Facultad Tecnológica, Colombia.

E-mail: ahernandezc@udistrital.edu.co

ORCID: <https://orcid.org/0009-0004-5392-0529>

CVLAC: https://scienti.minciencias.gov.co/cvlac/visualizador/generarCurriculoCv.do?cod_rh=0002142437

² Ph.D. in Educational Sciences, Ph.D. in Applied Linguistics, Postdoc in Cognition.

E-mail: jesabyb@udistrital.edu.co

ORCID: <https://orcid.org/0000-0002-4493-4783>

CVLAC: https://scienti.minciencias.gov.co/cvlac/visualizador/generarCurriculoCv.do?cod_rh=0000075809

Abstract

Introduction: The current state of wastewater treatment presents various challenges worldwide. In Colombia, municipal WWTPs face technical and operational limitations. This article is the result of research on the wastewater treatment system of Barichara, conducted at Universidad Francisco José de Caldas in 2025.

Problem: Currently, only about 10% of Colombian WWTPs comply with the parameters established for the discharge of treated wastewater into water sources, a worrying figure that alerts municipalities such as Barichara, where the plant is inoperative.

Objective: The research aims to identify the main difficulties in implementing municipal WWTPs in Colombia, using Barichara as a case study. It seeks to determine common factors that may affect similar systems across the country.

Results: Implementing these systems requires not only proper structural design but also a solid understanding of biological and chemical processes. Inefficiencies often arise from the lack of integration between design and local environmental or technical conditions.

Conclusions: One of the main problems is the selection of inappropriate treatment units that do not align with the specific characteristics of each municipality. Thus, the lack of synergy between structural and environmental design in the selection of treatment units is critical.

Originality: The research contributes by proposing adaptable, efficient, and sustainable alternatives that can be applied to small municipalities facing similar challenges.

Limitations: The analysis is based on a single case, which limits the direct generalization of the findings to other plants in the country.

Keywords: Wastewater treatment plant, WWTP, water discharge, chemical and biological processes, efficiency.

Resumen

Introducción: El tratamiento de aguas residuales enfrenta diversos desafíos a nivel global. En Colombia, las PTAR municipales presentan limitaciones técnicas y operativas. Este artículo es producto de una investigación sobre el tratamiento de aguas residuales en Barichara, desarrollada en la Universidad Francisco José de Caldas en 2025.

Problema: Actualmente, solo alrededor del 10% de las PTAR en Colombia cumplen con los parámetros establecidos para la descarga en cuerpos hídricos. Esta situación es crítica en municipios como Barichara, donde la planta se encuentra inoperativa.

Objetivo: La investigación busca identificar las principales dificultades en la implementación de PTAR municipales en Colombia, tomando como referencia el caso de Barichara, y establecer factores replicables en otras regiones del país.

Resultados: La implementación de estos sistemas requiere más que un diseño estructural adecuado; exige una comprensión integral de los procesos biológicos y químicos involucrados. Las ineficiencias surgen, en muchos casos, por la falta de articulación entre el diseño técnico y las condiciones ambientales o locales.

Conclusiones: Una de las principales falencias detectadas es la selección inadecuada de unidades de tratamiento, que no se ajustan a las características particulares del territorio. Esto afecta gravemente el desempeño de las plantas.

Originalidad: La investigación ofrece alternativas adaptables, eficientes y sostenibles, pensadas para municipios pequeños que enfrentan desafíos similares.

Limitaciones: El análisis se basa en un único caso, lo que restringe la generalización directa de los resultados a otras plantas del país.

Palabras clave: Plantas de Tratamiento de Aguas Residuales, PTAR, descarga de agua, procesos químicos y biológicos, eficiencia.

Resumo

Introdução: O tratamento de águas residuais enfrenta diversos desafios em todo o mundo. Na Colômbia, as estações de tratamento de águas residuais (ETARs) municipais apresentam limitações técnicas e operacionais. Este artigo é fruto de uma pesquisa sobre tratamento de águas residuais em Barichara, realizada na Universidade Francisco José de Caldas em 2025.

Problema: Atualmente, apenas cerca de 10% das ETARs na Colômbia atendem aos parâmetros estabelecidos para o lançamento em corpos d'água. Essa situação é crítica em municípios como Barichara, onde a estação está inoperante.

Objetivo: Esta pesquisa busca identificar as principais dificuldades na implementação de ETARs municipais na Colômbia, utilizando o caso de Barichara como referência, e estabelecer fatores que possam ser replicados em outras regiões do país.

Resultados: A implementação desses sistemas requer mais do que apenas um projeto estrutural adequado; exige uma compreensão abrangente dos processos biológicos e químicos envolvidos. As ineficiências surgem, em muitos casos, da falta de alinhamento entre o projeto técnico e as condições ambientais ou locais.

Conclusões: Uma das principais deficiências identificadas é a seleção inadequada de unidades de tratamento, que não são adequadas às características específicas do território. Isso afeta seriamente o desempenho das estações.

Originalidade: A pesquisa oferece alternativas adaptáveis, eficientes e sustentáveis, projetadas para pequenos municípios que enfrentam desafios semelhantes.

Limitações: A análise é baseada em um único caso, o que limita a generalização direta dos resultados para outras estações do país.

Palavras-chave: Estações de Tratamento de Esgoto, ETE, descarga de água, processos químicos e biológicos, eficiência.

INTRODUCTION

The current situation of wastewater treatment represents several challenges worldwide. In Colombia, the national report on the coverage of water, sewerage, and sanitation services reveals worrying figures of non-compliance with the standards established for wastewater discharges in both urban and rural areas. In 2023, members of the Fifth Commission of the House of Representatives, in a political control debate, raised several questions to the then Vice Minister of Water and Basic Sanitation, Aníbal Pérez García, regarding the frequent problems in the operation of Wastewater Treatment Plants (WWTPs) [1]. At present, many municipalities have these structures that, far from fulfilling their purpose of treating wastewater and delivering water in optimal conditions to the receiving body, have become the commonly known “white elephants.” The fact that these problems occur—initially seen from a political perspective—has a direct effect on the living conditions of the population by affecting public health and the environment, since the essential human right to basic sanitation includes not only access to toilets but also the proper management of waste generated in such a way as to ensure a dignified life.

The municipality of Barichara, in Santander, presents difficulties in terms of the effective implementation of its wastewater treatment plant, facing various problems that have left it inoperative since its delivery. Being a case that reflects a broader pattern of challenges in the implementation and operation of wastewater treatment systems at the municipal level in Colombia, Barichara will serve as a case study in this article, providing a concrete analysis of the challenges in the implementation and operation of wastewater treatment systems. In this context, it is crucial not only to identify existing problems but also to seek innovative and sustainable solutions focused on the particular needs of the municipalities where these systems are to be implemented, ensuring that they are appropriate in economic, social, and environmental terms. In this way, this article uses research conducted on the WWTP of Barichara to determine the difficulties in its implementation and their relationship to the difficulties encountered in the implementation of municipal wastewater treatment plants in Colombia. This evaluation will provide a frame of reference to identify the deficiencies and challenges that may arise in the operation of these hydraulic structures.

Although there is applicable regulation that establishes a road map through which this type of hydraulic structure can be designed—which will be evaluated later—it is important to keep in mind the context in which they are developed when structuring and designing these projects. Each project has differences and characteristics, where the economic, social, political, and technological conditions that guarantee the effectiveness of the system's operation are not the same. The case of the municipality of Barichara allows for an evaluation that highlights the importance of these aspects in the structuring of wastewater treatment plants.

Moreover, by including a more detailed evaluation, it is possible to show that there are currently less complex systems that can be easily adapted to different conditions, making them more viable, economical, sustainable over time, and requiring less maintenance.

1. LITERATURE REVIEW

According to figures from the United Nations (UN), the Regional Office for the Americas of the World Health Organization (WHO), the Pan American Health Organization (PAHO), and the Superintendencia de Servicios Públicos Domiciliarios, the basic sanitation problem is not only alarming at the regional level but also worldwide. Within the context of the difficulty faced by basic sanitation is the adequate management of the waste produced, and it is here where Wastewater Treatment Plants (WWTPs) play a fundamental role. These hydraulic structures, of great relevance in environmental and public health terms, have shown significant variation in their development and efficiency among regions due to economic differences and technological capacity (Fig. 1). In developed countries in Europe, North America, and some parts of Asia, WWTPs employ advanced technologies that not only comply with environmental policies but also allow the reuse of water, energy, and sludge resources. In contrast, in developing countries in Asia, Africa, and Latin America, the implementation of these hydraulic structures still faces great challenges in terms of efficiency and coverage.

In Colombia, WWTP coverage has improved in urban areas. However, in rural areas, coverage is still insufficient, leading to the discharge of untreated wastewater into rivers and streams, which contributes to the contamination of water bodies and environmental pollution, thereby negatively affecting public health [2]. The situation in Barichara, in the department of Santander, is a clear example of the deficiencies in the implementation and operation of WWTPs. Despite the high investment of economic resources and the time dedicated to the construction of the plant, it has never entered effective operation, maintaining the problem of wastewater discharge without adequate treatment. This case is evidence of the sanitation challenges faced by the country's municipalities. Most of the wastewater treatment plants in Colombia, including the one in the municipality of Barichara, do not comply with the parameters established for the discharge of treated wastewater due to the lack of synergy between environmental and structural issues during any stage of the process, whether in the selection of the system to be implemented, the construction and implementation stage—where failures or difficulties of a constructive or even political nature occur—or in the adoption of less complex systems that could improve the efficiency and sustainability of these plants at the municipal level. This situation will be evaluated in detail during the development of this article.

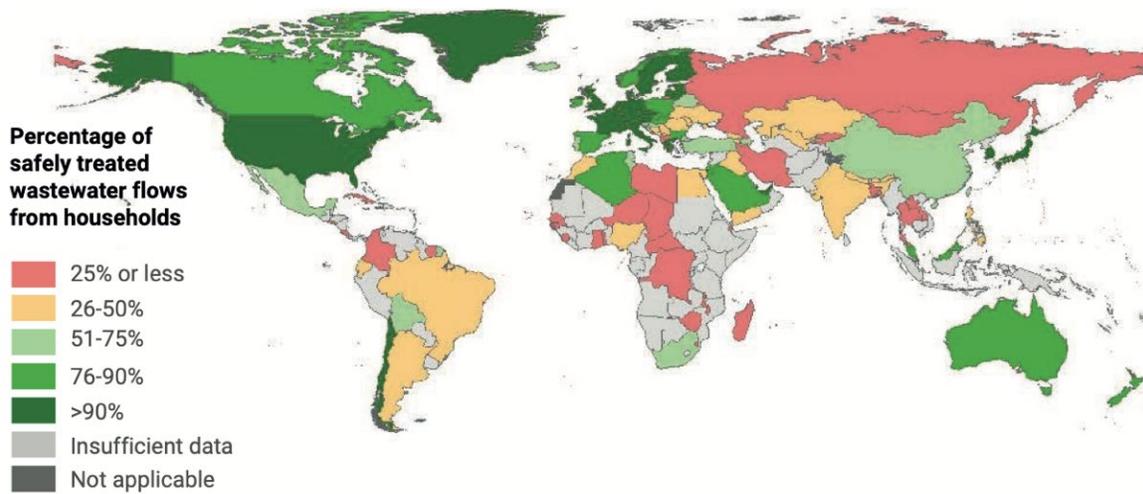


Fig. 1. Estimated proportions of adequately treated household wastewater. [3]

1. The regulations in Colombia for wastewater management are based on Law 99 of 1993, which establishes the general framework for environmental policy in Colombia and creates the National Environmental System (SINA). This law assigns responsibilities to territorial entities for water management and wastewater treatment and is regulated by Decree 1076 of 2015. Decree 3930 of 2010 establishes discharge management criteria and requires wastewater to be treated before discharge into water bodies, while Resolution 631 of 2015 sets the parameters and maximum permissible limit values for point discharges to surface water bodies and public sewage systems. This regulatory framework provides the roadmap for the planning, design, and construction of wastewater treatment plants in the country. In Colombian municipalities, planning for water resource management, including the location and development of infrastructure such as wastewater treatment plants (WWTPs), must be included in the Land Use Plan (POT), as well as the development and implementation of Sanitation and Wastewater Management Plans (PSMV), which are specific to wastewater management and must consider the construction, operation, and maintenance of WWTPs. The Corporations Autónomas Regionales (CARs) are responsible for authorizing and supervising compliance with these environmental regulations at the regional level, including the approval of WWTP projects [4].
2. The implementation and operation of a Wastewater Treatment Plant (WWTP) require detailed planning and constant monitoring to ensure effectiveness and sustainability. Planning involves evaluating several factors, such as selecting the appropriate location, determining the treatment capacity for the projected population's wastewater volume, adapting the design and technology to the

local context, and ensuring compliance with current environmental regulations. It also requires constant follow-up with trained personnel during the operational stage through continuous monitoring to evaluate the quality of the treated water and the safe management of the sludge generated, thereby avoiding additional environmental impacts that may arise from the treatment process. Planning and follow-up together enable the development of an efficient system with the capacity to adequately manage not only wastewater but also the resources obtained from the process, while complying with current environmental regulations, environmental policies, and the objectives of the 2030 Agenda.

3. **1. METHODOLOGY**

This research was developed in two main stages. Section 4 presents the first stage, which consists of an assessment and understanding of the overall situation. This begins with a detailed identification of the general situation of wastewater treatment plants, primarily with a national focus but also including relevant aspects of the international context. Subsequently, a contextual analysis is conducted for the case of Barichara. Technical visits were made to the treatment plant facilities in the municipality, where the overall condition of the plant was recorded and documented. As part of this assessment, photographic records and technical documentation such as audit reports, operating reports, and contracts were collected. Additionally, meetings were held with experts responsible for conducting technical assessments of the infrastructure.

4. Following the overall assessment, research was conducted to review the applicable regulations and rules for the municipal context and determine the parameters and maximum permissible values for point discharges to surface water bodies in Colombia. From this review, the system's shortcomings could be identified by comparing them with these regulatory limits. This also allowed each of the treatment plant's components to be compared separately against existing regulations.
5. Finally, in the second stage of the analysis, a comparative evaluation of alternative wastewater treatment systems was conducted, taking as a starting point the technical and operational results obtained in the diagnostic assessment of the Barichara municipal treatment plant. This exercise allowed not only for the comparison of local conditions with other existing technologies but also for assessing the relevance and viability of solutions applied in international contexts, especially in developed countries, where the planning and design of these systems have advanced toward more sustainable, efficient, and context-adapted approaches.

6. RESULTS

The United Nations revealed in the 2022 monitoring report of the 2030 Agenda that more than 3.5 billion people did not have safe sanitation management [3], compared to Goal 6: Clean Water and Sanitation, which proposes to ensure the

availability and sustainable management of water and sanitation for all [5]. Meanwhile, the Regional Office for the Americas of the World Health Organization and the Pan American Health Organization (2023), during the Inter-American Sanitation Day, reported that 50.8% of Latin America and the Caribbean do not have safely managed sanitation. At the same event, Patricia Segurado, PAHO's Regional Water and Sanitation Advisor, emphasized that it is as important to have sewerage services as it is to ensure the final treatment of wastewater and its monitoring [5].

In Colombia, the *National Report on Coverage of Water, Sewerage, and Sanitation Services for 2022*, presented by the Superintendencia de Servicios Públicos Domiciliarios, found that in urban areas 531 municipalities have coverage of between 90% and 100%, 7 municipalities have coverage of less than 50%, and 7 municipalities have coverage of less than or equal to 15%. In rural areas, only 27 municipalities have coverage between 90% and 100%, 829 municipalities have coverage of less than or equal to 30%, and 18 of the country's capitals have between 0% and 5% coverage in their rural areas (Fig. 1).

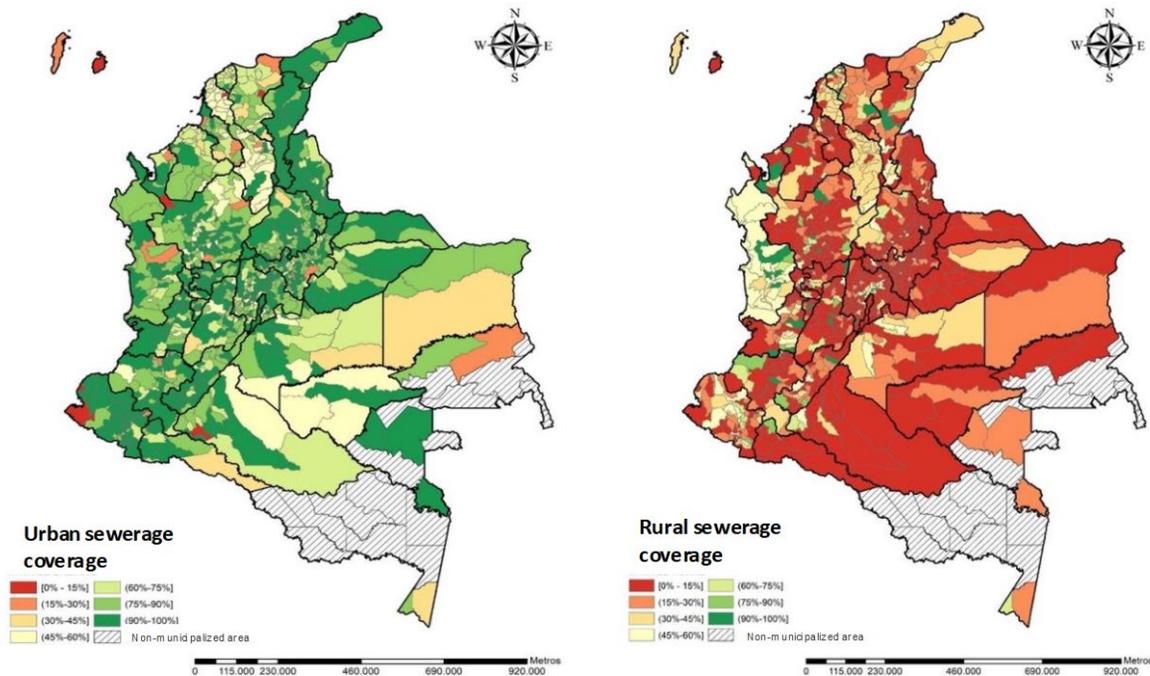


Fig. 2. Urban and rural sewerage coverage in force 2022. [2]

Additionally, the report revealed that out of the 1,108 active sewerage service providers, only 706 treat wastewater, corresponding to 63.71%. In other words, the remaining 36.28% of providers do not treat the wastewater produced in the

country. A total of 728 Wastewater Treatment Plants (WWTPs) were identified nationwide; however, only 374 of these systems, corresponding to 49%, are reported in the Single Information System of Household Public Services (SUI, for its acronym in Spanish). Furthermore, the report estimated under the indicator called “percentage of treated urban wastewater” that by 2022, only 43.91% of the wastewater generated in the country was treated [2].

On the other hand, based on Resolution 631 of 2015 of the Ministry of Environment and Sustainable Development, “Whereby the parameters and maximum permissible limit values in point discharges to surface water bodies and public sewage systems are established and other provisions are issued” (Table 1), the concentration values of the Biochemical Oxygen Demand (BOD₅), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS) parameters were studied. The results showed that for the Biochemical Oxygen Demand (BOD₅) parameter, whose admissible range is between 70 mg/L and 90 mg/L, out of 1,449 reports only 211 are within the permissible range, corresponding to 14.5% of the discharges. For the Chemical Oxygen Demand (COD) parameter, whose admissible range is between 150 mg/L and 180 mg/L, out of 1,517 reports only 150 are within the permissible range, corresponding to 9.88% of the discharges. Finally, for Total Suspended Solids (TSS), the maximum admissible limit is 90 mg/L, and it was determined that the total solids removal values are around 100 mg/L (Fig. 3) [2].

TABLE I
Maximum permissible limits for wastewater quality

Parameter	Units	Maximum permissible limits in wastewater discharges from public sewer service providers to surface water bodies, with a load less than or equal to 625 kg/day BOD₅	Maximum permissible limits in wastewater discharges from public sewer service providers to surface water bodies, with a load less than or equal to 3000 kg/day BOD₅
Biochemical Oxygen Demand (BOD ₅)	mg/L O ₂	70	90
Chemical Oxygen Demand (COD)	mg/L O ₂	150	180

Source: Adapted from [6]

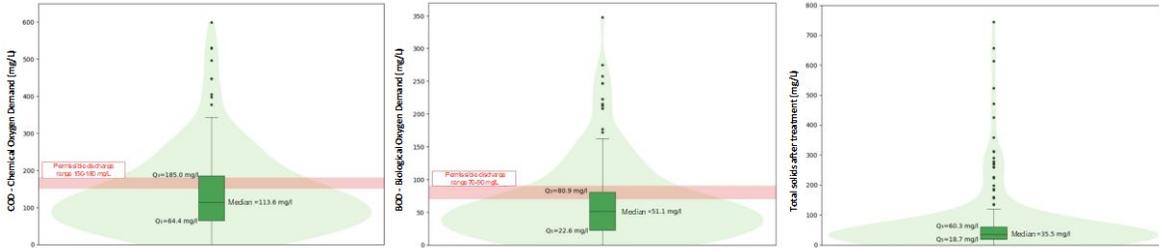


Fig. 3. Maximum permissible limits for wastewater quality. [2]

Although the country has made efforts to comply with environmental policies, based on data from the *National Report on Coverage of Water, Sewage, and Wastewater Services*, it is correct to infer that Colombia currently has a wastewater discharge problem into water tributaries. As of 2022, only 43.91% of the wastewater generated in the country received treatment. In addition, the number of discharges whose parameters complied with the admissible ranges is considerably low: only 14.5% comply with the admissible ranges for Biochemical Oxygen Demand (BOD₅) and only 9.88% with the ranges for Chemical Oxygen Demand (COD). In other words, only about 10% of the country's discharges comply with the parameters established in Resolution 631 of 2015. From the international perspective, the need to improve these water treatment systems is evident, while from the national perspective, problems can be identified, starting with providers that do not treat the waste generated, continuing with systems that do not report the efficiency of the treatments carried out, and ending with inoperative systems.

Now, taking the problem to a context that allows the identification of the general characteristics on which this study has been focused, municipal analysis is a useful tool for specific evaluation. The municipality of Barichara, in the department of Santander, Colombia, has an area of 134 km² and an altitude of 1,300 m above sea level. The area is characterized by a bimodal rainfall regime, with heavy rains between April–May and September–October, and dry periods between June–August and November–February. *Empresa de Servicios Públicos de Barichara E.P.B. E.S.P.* is responsible for providing water, sewerage, and sanitation services in the municipality, with a coverage rate of 100% in the urban area, serving a total of 1,221 subscribers. The municipality's sewerage system is gravity-driven and combined; that is, it receives both domestic wastewater (ARD) and rainwater, which are conveyed to the wastewater treatment plant through two networks. The first consists of 8-inch and 10-inch diameter stoneware pipes, with lengths of 1,147 meters and 239.21 meters, respectively. The second corresponds to the network called *Caño de Cuadrado*, made of stone, 2 meters deep, 1.5 meters wide, and 345.7 meters in total length [7].

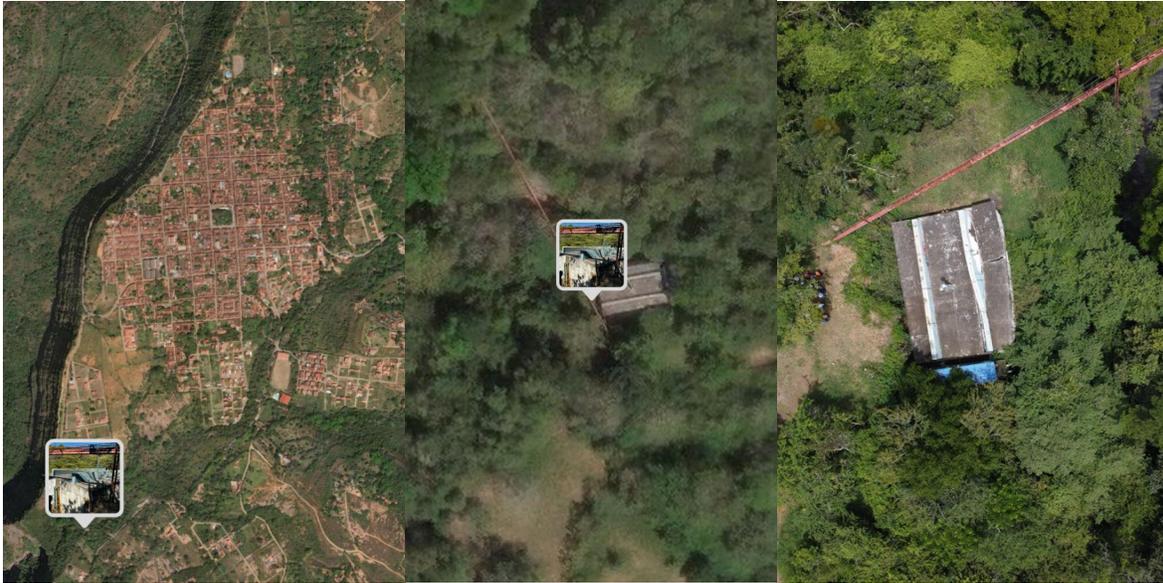


Fig. 4. Location of the Wastewater Treatment Plant of the municipality of Barichara. [8]

At the beginning of 2012, *Empresa de Servicios Públicos de Barichara* awarded the construction contract for the Wastewater Treatment Plant in the municipality of Barichara, department of Santander, to the contractor *Civiles y Ambientales Ingenieros Ltda. (CIAMING LTDA)* for \$695,009,938.64 MCTE, with an execution term of nine months starting on March 8, 2012. However, the project underwent four schedule modifications, with final delivery on August 18, 2015, and a budget addition of \$594,724,362.41 MCTE, for a total of \$1,320,371,454.71 MCTE and about three and a half years of execution, in a project that never entered operation [9].

The Wastewater Treatment Plant (WWTP) is located in the village of El Salitre, southeast of the municipal capital (Fig. 4), at coordinates N: 6°37'29", E: 73°13'41", at an altitude of 1,206 meters above sea level. It is built in reinforced concrete and has two treatment phases: preliminary and secondary (Fig. 5). Preliminary treatment consists of an inlet channel, screening grids, a sand trap, and a grease trap, while secondary treatment consists of distribution boxes, an upflow anaerobic reactor (UASB), drying beds, and a methane gas burner. The treated water is discharged into the Barichara Ravine in the La Vega sector, upstream of *Salto del Mico* (Fig. 6), a tourist site in the municipality.



Fig. 5. Status of Wastewater Treatment Plant (WWTP) of the municipality of Barichara. [8]



Fig. 6. Discharge of treated water into the Quebrada Barichara stream. [8]



Fig. 7. Status of screening screens, Barichara WWTP. [8]

The following is an analysis to identify the reasons for the inefficiency of the wastewater treatment plant of the municipality, since it was determined that the discharges of the plant are not complying with the admissible ranges for the parameters of chemical oxygen demand (COD) and total suspended solids established in Resolution 631 of 2015 of the Ministry of Environment and Sustainable Development Table 2, since according to the characterization Table 3, a value of 190.05 mg/L O₂ in chemical oxygen demand (COD) is being recorded in the discharge, exceeding the allowable range of 180 mg/L O₂ by 10.05 mg/L O₂, as well as for total suspended solids is exceeded by 40.35 mg/L outside the limit of 90 mg/L when 130.35 mg/L is reported.

TABLE II
Permissible ranges of parameters for domestic and non-domestic wastewater discharge

Parameter	Units	Domestic wastewater – ARD from individual sanitation solutions for single-family and two-family homes	Domestic wastewater – ARD and wastewater (ARD – ArmD) from public sewer service providers to surface water bodies with a load less than or equal to 625 kg/day BOD ₅
General			
pH	pH Unit	6.0 to 9.0	6.0 to 9.0
Chemical Oxygen Demand (COD)	mg/L O ₂	200	180
Biochemical Oxygen Demand (BOD ₅)	mg/L O ₂	100	90
Total Suspended Solids (TSS)	mg/L	100	90
Settleable Solids (SSE)	mg/L	1.0	0.5
Grease and Oils	mg/L	30	10
Hydrocarbons			
Total Hydrocarbons (HTP)	mg/L	Analysis and report	Analysis and report
Phosphorus Compounds			
Orthophosphates (P-PO ₄ ³⁻)	mg/L	Analysis and report	Analysis and report
Total Phosphorus (P)	mg/L	Analysis and report	Analysis and report
Nitrogen Compounds			
Nitrates (N-NO ₃ ⁻)	mg/L	Analysis and report	Analysis and report
Nitrites (N-NO ₂ ⁻)	mg/L	Analysis and report	Analysis and report

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Ammoniacal Nitrogen (N-NH ₃)	mg/L	Analysis and report	Analysis and report
Total Nitrogen	mg/L	Analysis and report	Analysis and report

Source: Adapted from [6]

TABLE III
Characterization of physicochemical parameters of the effluent

Parameter	Units	Permissible Range	PTAR Barichara Concentration	Rating
General				
pH	pH Unit	6.0 to 9.0	6.465	Complies
Chemical Oxygen Demand (COD)	mg/L	180	190.5	Does not comply
Biochemical Oxygen Demand (BOD ₅)	mg/L	90	44.75	Complies
Total Suspended Solids (TSS)	mg/L	90	130.35	Does not comply
Settleable Solids (SSE)	mg/L	0.5	0.05	Complies
Grease and Oils	mg/L	20	8.9	Complies
Hydrocarbons				
Total Hydrocarbons (HTP)	mg/L	Analysis and report	3.15	Not reported
Phosphorus Compounds				
Orthophosphates (P-PO ₄ ³⁻)	mg/L	Analysis and report	1.86	Not reported
Total Phosphorus (P)	mg/L	Analysis and report	3.505	Not reported
Nitrogen Compounds				
Nitrates (N-NO ₃ ⁻)	mg/L	Analysis and report	0.03	Not reported
Nitrites (N-NO ₂ ⁻)	mg/L	Analysis and report	0.005	Not reported
Ammoniacal Nitrogen (N-NH ₃)	mg/L	Analysis and report	0.14	Not reported
Total Nitrogen	mg/L	Analysis and report	23.45	Not reported

Source: Adapted from[7]

Beginning the diagnosis of the Barichara wastewater treatment plant, regarding the preliminary treatment system, during the visit, it was found that the screening grids, which are responsible for retaining the coarse and fine solids entering the system, are collapsed due to a lack of maintenance Fig. 7. As well as for the other components of the preliminary system: sand trap, for the removal of

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sands and solids in sedimentation and grease trap, removal systems for the removal of solids in sedimentation and grease traps.

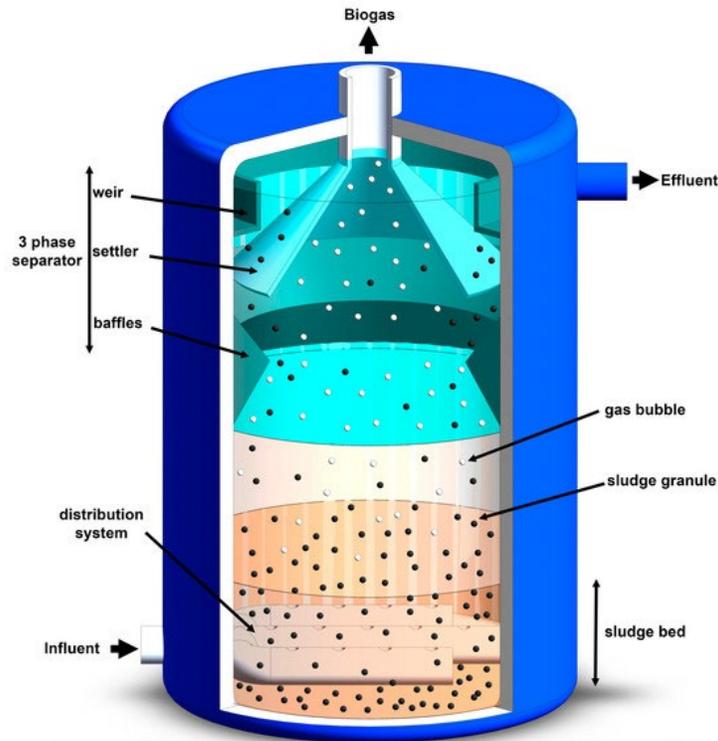


Fig. 8. Diagram of up flow anaerobic reactor. [10]

The secondary treatment system consists of the distribution boxes, the upflow anaerobic reactor (UASB), the drying beds, and the methane gas burner. Starting with the upflow anaerobic reactor (UASB), it has three zones: the sludge bed zone, where the microorganisms that degrade the organic matter present in the wastewater are concentrated; the sludge blanket zone, where the microorganisms are dispersed throughout the reactor; and finally, the gas-solid-liquid zone, where the treatment products are separated (Fig. 8). This is a biological water treatment system because different groups of microorganisms are involved in the transformation stages of organic matter, which will be explained below.

The upflow anaerobic reactor (UASB) is an anaerobic treatment that develops through four main stages (Fig. 9). The first is hydrolysis, the stage in which macromolecules are broken down. In this process, hydrolytic bacteria act to degrade large molecules of organic matter into simpler compounds, converting carbohydrates into simple sugars, proteins into amino acids, and lipids into fatty acids and glycerol. The second stage is acidogenesis, in which the formation of organic acids and soluble compounds takes place, involving acidogenic bacteria that convert the products obtained in the hydrolysis stage into organic acids, alcohols, and other compounds. As a result, volatile fatty acids (VFAs), alcohols, CO_2 , and H_2 are obtained from sugars and amino acids, while VFAs and glycerol are obtained from lipids. The third stage, acetogenesis, involves converting organic acids into acetate, CO_2 , and hydrogen. In this stage, acetogenic bacteria

transform the previously obtained products as follows: volatile fatty acids into acetate + CO₂ + H₂, and alcohols into acetate + H₂. The final stage, methanogenesis, produces methane and carbon dioxide. In this stage, methanogenic archaea generate methane + CO₂ from acetate, and methane + H₂ + CO₂ + H₂O from H₂ + CO₂ [11].

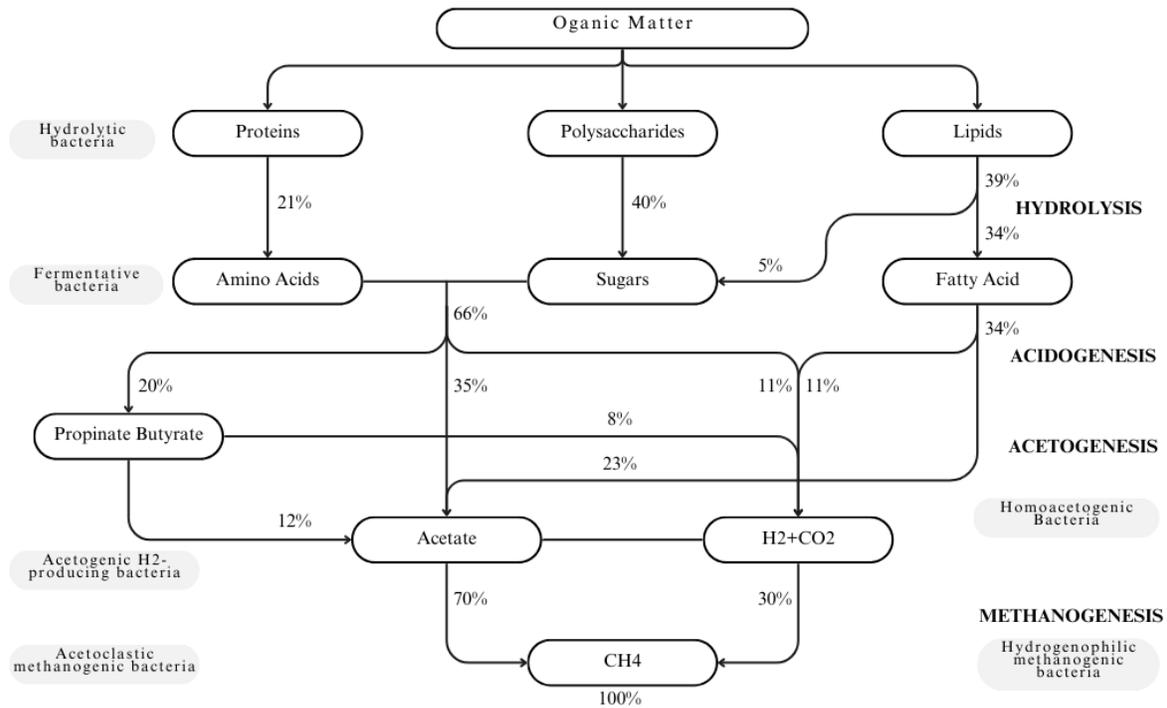


Fig. 9. Transformation of organic matter in up flow anaerobic reactor. [12]

It is important to point out that for the treatment to be efficient, it is necessary to maintain optimal conditions for microbial activity, such as a pH between 6.5 and 8, especially in the methanogenesis stage, because methanogenic archaea are very sensitive to changes in pH. The temperature should commonly range between 35 °C and 37 °C. The VFA/alkalinity ratio must also be controlled, since an excess of volatile fatty acids can inhibit methanogenesis. The retention time should be between 6 and 24 hours, depending on the wastewater and organic load, as excessively high values can cause acidification of the system and lead to failures [11].

At this point, it should be noted that in the municipality of Barichara, as in many other municipalities in the country, it is not possible to guarantee these requirements because, as mentioned above, the sewage system is combined. In the dry season, the effluent is concentrated, while in the rainy season it is diluted, which generates changes in factors such as pH, temperature, and organic load. These changes in the system cause inhibition of the methanogenic bacteria, resulting in the loss of the bacterial load in the sludge and blankets of the reactor.

This negatively affects the efficiency of the treatment, since the recovery of these bacterial loads can take up to six months, with acidification of the system being one of the main causes of operational failure in anaerobic reactors.



Fig. 10. Barichara WWTP drying beds. [13]

As for the drying beds, devices that remove a sufficient amount of water from the sludge so that it can be handled as solid material, according to information gathered during the technical visit, have always been found to be empty, since due to the inefficiency of the previous steps in the treatment process, it has not been possible to obtain biomass in the Process Fig. 10. Finally, as for methane gas, responsible for converting the biogas methane (CH_4) into, during the visit, it was identified that the methane gas burner has gas ducts in an advanced state of deterioration, showing cracks, longitudinal displacements, and even detachment of the concrete plate Fig. 11. It can also be seen that the burner has not been put into operation since its installation Fig. 12, as it still has the plastic film with which the new element is covered, a film that would have been incinerated when it was put into operation after reaching the high temperatures during the burning of methane gas.



Fig. 11. State of methane gas pipelines. [8]



Fig. 12. Methane gas burner. [8]

However, it is important to highlight the advanced state of deterioration of the concrete structure that makes up the treatment plant, which shows cracks of considerable dimensions along the system plate, and displacement from its original position, as well as detachments in the pipe couplings Fig. 13. After the observations and the visit made, it was determined that this structure has not been in operation since its delivery, which was made in the same terms, arguing that the contractor had started up late due to the formation the bacterial load inside the reactor, a problem that persists today and that in addition to affecting the ecosystems due to discharges outside the established ranges, affects the community in the area surrounding the plant due to the strong odors that are present in the plant.



Fig. 13. Status of Barichara wastewater treatment plant. [8]

6. DISCUSSION

The results obtained from the analysis of the wastewater treatment plant (WWTP) of the municipality of Barichara allow the establishment of patterns related to the difficulties that may arise in the implementation of sanitation systems at the municipal level in Colombia. Although the Barichara WWTP applies the parameters established by the Technical Regulations for the Drinking Water and Basic Sanitation Sector (RAS 2017) regarding the structuring of preliminary, primary, and secondary treatment components, these do not meet the specific needs of the municipality. As noted above, the main component of the plant for the treatment of organic matter is the upflow anaerobic reactor (UASB), which requires specific conditions in the influent to guarantee the efficiency of organic matter removal. These requirements cannot be met in the municipality due to its combined storm and sanitary sewage system, resulting in the loss of sludge beds and layers. Consequently, the operation of this system is not suitable for the municipality's hydraulic infrastructure, and the components selected for preliminary and secondary treatment do not provide adequate access for maintenance.

Thus, the case of Barichara highlights a relevant point in the adoption of municipal wastewater treatment systems. Although in structural and environmental terms the plant complies with current regulations in the selection and composition of units, this composition does not necessarily consider the chemical and biological factors involved in the wastewater treatment process. It is essential to understand the transformation of organic matter by microbiotas so that these systems are implemented only in locations where the conditions required to sustain the microbial load—and thus ensure the quality of the effluent—can be guaranteed.

Considering the needs of municipalities, it is pertinent to adopt treatment units in such a way that the requirements of each component are met, while avoiding systems that rely on pumps, motors, or other mechanisms that involve high costs and become unsustainable for certain municipalities. It is therefore appropriate to implement units that operate by gravity or hydraulically, making the systems economical, sustainable, efficient, and easy to maintain.

While these issues could be addressed by correctly selecting and implementing additional units for the existing infrastructure, such measures would be costly and, in many cases, unsustainable in the long term. However, an efficient, sustainable, economical, and innovative solution has been developed in countries such as Germany and is currently being replicated in several parts of the world due to its effectiveness in diverse contexts. This approach consists of wastewater treatment systems based on artificial wetlands, in which reductions in Biochemical Oxygen Demand (BOD) and suspended solids occur through microbial activity, while phosphorus and nitrogen are removed through denitrification processes and plant absorption. These mechanisms are not only efficient but also highly environmentally friendly, as they utilize organic matter to nourish surrounding ecosystems and do not require chemical additives [14]. Such systems are economical in maintenance and operation, efficient for both domestic and industrial wastewater, environmentally friendly by contributing organic matter to ecosystems, and even harmonious with the landscape.

In Fronhausen, Germany, a wastewater treatment system using artificial wetlands was implemented [15]. This system was designed with an area of 8,145 m² for a population of 5,000 inhabitants, allowing compliance with the strict BOD and COD parameters established by the European Union. Although the required area is significant, it is due to the need to ensure year-round operation, including during freezing seasons, which are not a concern in tropical countries such as Colombia. Therefore, this system could be particularly appropriate and replicable in towns of similar size, such as Barichara, which has 2,617 inhabitants (Fig. 14).



Fig. 14. Advanced wastewater and sludge treatment using artificial wetlands in Fronhausen, Germany. [15]

6. 6. CONCLUSIONS

Currently, there are challenges in wastewater discharges into water bodies worldwide—challenges that have been addressed by the United Nations through the implementation of Goal 6 of the *2030 Agenda*, which seeks to ensure clean water and sanitation for all. In the Colombian case, figures from the Superintendency of Public Utilities reveal that only about 10% of wastewater discharges comply with the parameters established by the Ministry of Environment and Sustainable Development.

7. The research conducted on the wastewater treatment plant (WWTP) in the municipality of Barichara, Santander, identified patterns that can be replicated in many other municipalities in the country. These municipalities also have systems that do not guarantee the quality of the discharge and present problems such as the selection of treatment units inappropriate for the specific characteristics of the area where the project is to be developed. This reflects the lack of synergy between the structural and environmental design of the facilities.
8. Although the implementation of traditional units into the existing infrastructure could improve the quality of the discharge, it is pertinent to explore the adoption of highly efficient systems that have proven to be economical, effective, sustainable, and adaptable to the geographical conditions of the projects. Artificial wetland treatment systems in Europe and Asia have demonstrated for several years that they meet discharge standards and represent a suitable option for the treatment of both domestic and industrial wastewater.
9. In this regard, it is important to recall that the primary objective of a Wastewater Treatment Plant (WWTP) is to adequately treat wastewater in order to mitigate its environmental impact, particularly on receiving water bodies. Therefore, the formulation and implementation of these systems should focus primarily on ensuring the quality of the final discharge, rather than strictly adhering to regulations that prescribe specific units or processes without considering their technical, operational, or economic feasibility in specific local contexts. Consequently, regulations should evolve toward an outcome-based approach that promotes effective environmental results, rather than merely ensuring formal compliance with structural or procedural requirements.

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