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State-of-the-art review on WWTPs in Antioquia: levels, technologies, flaws and operational setbacks[1]

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Abstract

The number of wastewater treatment plants (WWTPs) in Antioquia (Colombia) increased 74 % over the last nine years. This increase brought to light we need for a unified guide to prevent flaws in the future WWTPs. Therefore we set out to design a guide to meet this new need. To achieve this design we had four main stages. First, we chose the 89 WWTPs from previous experience that we had in the operational stage. Second, we classified these WWTPs into levels and technologies. Third, we described various flaws in these WWTPs. Fourth, we designed a guide with these WWTPs technologies mostly used in Antioquia. Here we described that these WWTPs mostly used a combination of various levels and technologies. These levels were pre-treatment, primary treatment, secondary treatment and sludge treatment. These technologies were primary sedimentation basins (with inclined plates), UASB reactors, anaerobic packed-bed reactors, anaerobic sludge digesters and conventional sands beds. These WWTPs mostly served a population of less than 30.000. And these WWTPs had various flaws and operational setbacks. These flaws were the inappropriate localization of these WWTPs, low retention times in these anaerobic packed-bed reactors and the lack of proper size in these conventional sands beds. These setbacks were the unequal distribution

1 Artículo de revisión derivado del proyecto de investigación *State-of-the-art review on WWTPs in Antioquia: levels, technologies, flaws and operational setbacks y Guía de diseño conceptual y operación de plantas de tratamiento de aguas residuales domésticas en pequeñas comunidades para profesionales*. Universidad de Antioquia, Medellín, Colombia. Ejecutado entre julio de 2019 y junio de 2022, proyecto adscrito al Grupo de Investigación en Gestión y Modelación Ambiental (GAIA), financiado por los autores.

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of influent and effluent collection in these UASB reactors and anaerobic reactors. We suggest that we could use this guide in 2 different ways. First, to prevent these flaws in the future WWTPs. Second, to improve the training guides for operators in charge of these WWTPs, which makes the operations more efficient.

Keywords: technologies, WWTPs, guide, flaws, operational.

Revisión del estado del arte de las PTAR en Antioquia: niveles, tecnologías, errores y problemas operativos

Resumen

El número de plantas de tratamiento de aguas residuales (PTAR) en Antioquia (Colombia) aumentó 74 % en los últimos nueve años. Este aumento nos mostró que necesitamos una guía para prevenir errores de diseño, instalación y operación en las futuras PTAR. Entonces diseñamos esta guía para satisfacer esta nueva necesidad. Para diseñar esta guía tuvimos cuatro objetivos. El primero, elegir 89 PTAR de la experiencia que teníamos en la fase operativa. El segundo, clasificar estas PTAR en niveles y tecnologías. El tercero, describir varios errores de diseño en estas PTAR. El cuarto, diseñar una guía para describir las tecnologías más usadas en Antioquia.

Aquí describimos que estas PTAR usaron una combinación de varios niveles y tecnologías. Estos niveles eran pretratamiento, tratamiento primario, secundario y tratamiento de lodos. Estas tecnologías eran sedimentadores primarios de alta tasa, reactores UASB, reactores PBR, reactores anaerobios de lodos y lechos de arena. Estas PTAR tenían una población menor a 30.000, varios errores de diseño y problemas operativos. Estos errores eran la inapropiada localización, los tiempos de retención hidráulicos bajos en los reactores PBR y los lechos de arena muy pequeños. Estos problemas eran el ingreso y salida desigual del agua en reactores UASB y PBR. Sugerimos usar nuestra guía de 2 maneras: la primera, para prevenir estos errores de diseño en las futuras PTAR. La segunda, para mejorar la capacitación de los operadores a cargo de estas PTAR para que las operaciones sean más eficientes.

Palabras clave: tecnologías, PTAR, guía, errores, operativos.

Revisão do estado da arte do PTAR em Antioquia: níveis, tecnologias, erros e problemas operacionais

Resumo

O número de estações de tratamento de esgoto (ETE) em Antioquia (Colombia) aumentou 74 % nos últimos nove anos. Este aumento nos mostrou que precisávamos de um manual para prevenir erros de design, instalação e funcionamento em futuras ETE. Por isso, desenhamos este manual para cumprir a esta nova necessidade. No design deste manual tínhamos quatro objetivos. Primeiro, escolher 89 ETE a partir da experiência que tínhamos na fase operacional. Segundo, classificar estas ETE em níveis e tecnologias. Terceiro, descrever vários erros de design nessas ETE. Quatro, desenvolver um manual para descrever as tecnologias mais usadas em Antioquia.

Aqui descrevemos que estas ETE usaram uma combinação de vários níveis e tecnologias. Estes níveis eram o pré-tratamento, o tratamento primário e secundário e o tratamento de lodos. Estas tecnologias eram tanques de sedimentação primária (com placas inclinadas), reatores UASB, reatores PBR, reatores anaeróbicos de lodos e leitos de areia. Estas ETE tinham uma população de menos de 30.000, vários erros de design e problemas operacionais. Estes erros eram localização inadequada, baixos tempos se retenção hidráulica nos reatores PBR e leitos de areia muito pequenos. Estes problemas eram a entrada e saída irregular de água nos reatores UASB e PBR. Sugerimos usar este manual de 2 maneiras. Primeira, para prevenir estes erros de design em futuras ETE. Segunda, para melhorar a formação dos operadores destas ETE para tornar as operações mais eficientes.

Palavras-chave: tecnologias, ETE, manual, erros, operacionais.

Introduction

Wastewater treatment in urban areas is essential to achieve safe and equitable sanitation (United Nations and Unesco, 2017; World Health Organization and UN-Habitat, 2018). In urban areas, sanitation requires sewer networks and unified wastewater treatment plants (WWTPs). In rural areas, sanitation requires a sewer network and onsite WWTPs. Unified WWTPs are larger than onsite WWTPs. Therefore international groups of people say that we need more WWTPs. These groups are the United Nations (UN) and Latin American Countries (LACs).

National institution such as the Departamento Nacional de Planeación (DPN) also says the same thing that we need more WWTPs. Although the DPN (Consejo Nacional de Política Económica y Social, 2020) stated that Colombia will need more advanced technologies in WWTPs to achieve safe and equitable sanitation. For example, the number of WWTPs in Antioquia (Colombia) increased 74 % over the last nine years (Cornare, 2017; Corantioquia, 2019a). This increase brought to light we need for a unified guide to prevent flaws in the future WWTPs. Also we need to arrange the existing WWTPs technologies to use this guide properly.

We know that these WWTPs use a combination of various levels and technologies. For example, Noyola *et al*. (2012) stated that WWTPs technologies used in LACs are stabilization lagoons, activated sludge, and up-flow anaerobic sludge blanket reactors (UASBRs). However, these LACs require to confront one of the greatest challenges in these WWTPs in urban areas so far. This challenge is to operate continuously these existing WWTPs technologies. Although the use of these WWTPs technologies depends on capital expenditures (CAPEX) and operational expenditures (OPEX).

This use of these WWTPs technologies such as UASBRs have gained significant ground in LACs (Von Sperling, 2016). For example, these UASBRs have lower CAPEX and OPEX savings than activated sludge. These CAPEX savings in UASBRs are in the range of 20 to 50 %. These OPEX savings in UASBRs are in the range of 40 to 50 % (Von Sperling & Chernicharo, 2005a; Chernicharo, 2006; Chernicharo *et al.*, 2015). Also Chernicharo *et al.* (2019) stated that WWTPs technologies in Brazil are UASBRs, activated sludge, and stabilization lagoons. This information is important because it helps us understand the prevalence of UASBRs in WWTPs in LACs, Colombia and urban areas.

We also know that three institutions are in charge of these WWTPs in Antioquia. These institutions are public services, city halls, and environmental agencies. However, they have not yet designed a unified set of guides to prevent flaws and ensure proper functioning of these WWTPs. The need for a unified set of guides is clear. And these guides should include what we know about these WWTPs technologies.

Therefore in this research we set out to achieve one main goal. This goal was to design a guide for the conceptual layout and operation of small WWTPs. Although there are governmental directives that govern WWTPs in a national level such as Ministerio de Ambiente y Desarrollo Sostenible. And there are guides at the national level such as Resolución 0330 de 2017. However, these guides are not always suitable to local WWTPs and not always used ideally. Therefore the need for a unified guide for WWTPs in Antioquia led us to design it. We also set out to answer one question: how can we prevent layout flaws in WWTPs for population of less than 30.000?

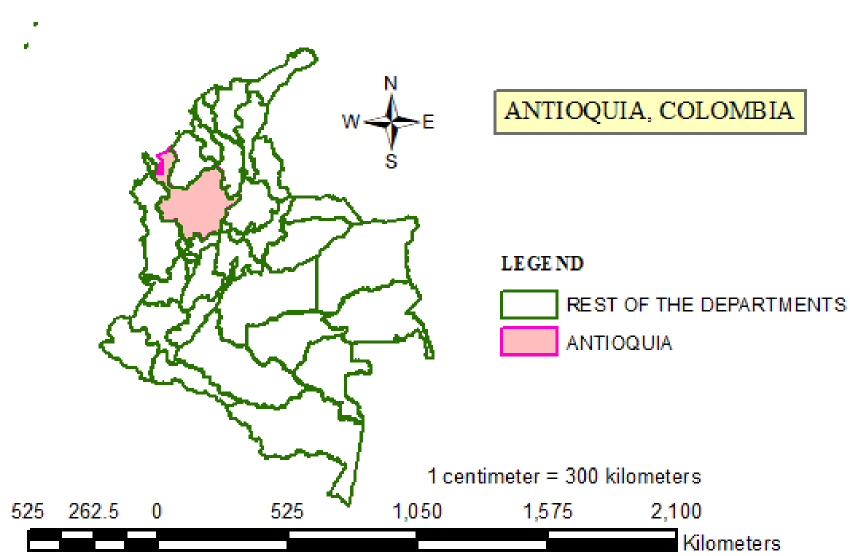
Methods

Convenience sample

To achieve this design, we had four main stages. The first stage was to choose a convenience sample of various WWTPs in Antioquia. It was the first stage for us because the advantage of the convenience sample was to choose these WWTPs in population of less than 30.000. Antioquia had 125 municipalities, which have 88 % of urban areas with population of less than 30.000 (González *et al.*, 2012). Antioquia is one of the 32 departments of Colombia. Therefore we also used three secondary stages to choose the sample of WWTPs. First, we chose 89 WWTPs from previous experience that we had in the operational stage (Fuentelsaz Gallego, 2012). And we knew various of these WWTPs before further classification. Second, we examined various WWTPs reports and blueprints from environmental institutions. Third, we arranged these 89 WWTPs in a data base to prevent classification flaws.

Although these 89 WWTPs meant that it was not possible to obtain the total number of the WWTPs in Antioquia from the environmental institutions (**Fig 1**). These institutions had not only a few tiny sliver of the population without WWTPs but also they supervised the layout and operational stages of these WWTPs. Although these institutions had various texts such as layout and brief reports, calculation sheets and guides to examine the WWTPs. And we used these texts to identify flaws in the WWTPs classification.

Note that we used a variation of colors to show the sample of 89 WWTPs. We used the violet color to show various municipalities in the metropolitan area. These municipalities had two large WWTPs. These WWTPs were Aguas Claras and San Fernando, which we did not use in this sample. We used blue color to show the rest of the municipalities without proper texts to examine the WWTPs.



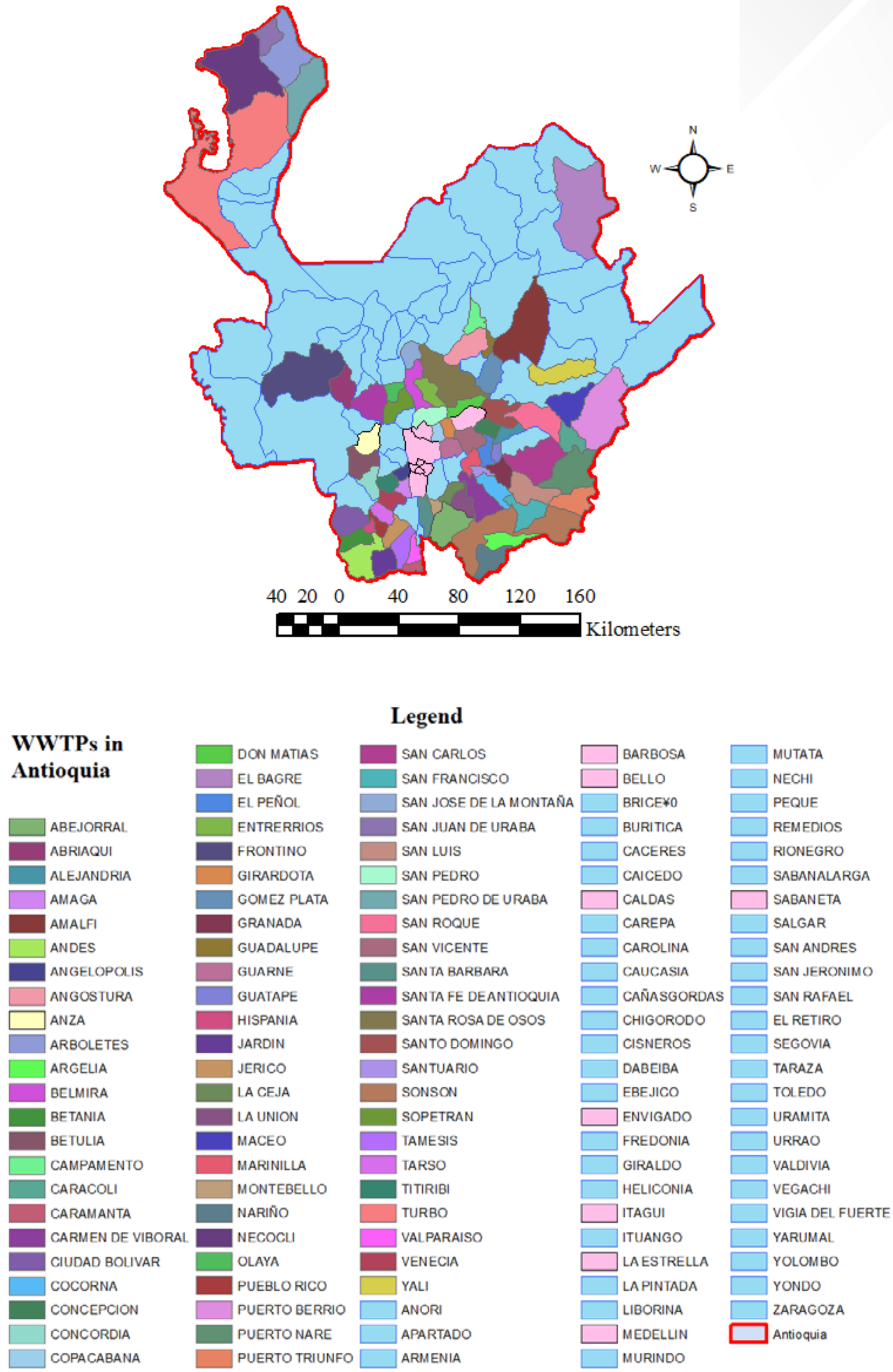


Figure 1. Localization of Antioquia, Colombia. The sample of WWTPs in Antioquia.

Note: Own elaboration.

WWTPs Classification

The second stage was to classify these WWTPs into a combination of various levels and technologies. It was the second stage for us because it was the most effective way to arrange these WWTPs. To classify these WWTPs we examined a combination of various academic texts. These texts were textbooks, handbooks, published reviews, some related research, book reviews, data base and brief reports of these WWTPs. We used these texts in four different ways. First, to arrange these WWTPs levels and technologies. Second, to discover various flaws in these WWTPs. Third, to examine various setbacks in these WWTPs. Fourth, to follow the continuous operation of these WWTPs.

Although various authors of these texts used variations in definitions to describe these WWTPs levels. These variations in definitions came to light after further classification of these WWTPs. One of these definitions that we faced was to distinguish between two levels. These levels were primary and secondary treatment. We distinguished primary from secondary treatment by understanding the process in each of these treatments. Here we followed Von Sperling & Chernicharo (2005a), Ortega de Miguel *et al.* (2010), and Qasim & Zhu (2018), definition of various WWTPs levels and technologies.

WWTPs flaws and operational setbacks

The third stage was to describe various flaws and operational setbacks in these WWTPs. It was the third stage for us because it was the easiest way to tell about the presence of these flaws and setbacks. To describe these flaws and setbacks we visited 20 of these 89 WWTPs in the start-up stage to verify their operational status. And we examined a combination of previous academic texts to know the layout and operation stages of these WWTPs technologies. We also described these flaws and setbacks to prevent future flaws.

Design of a guide

The fourth stage was to design a guide with the WWTPs technologies mostly used in Antioquia. It was the third stage for us because it was the most efficient way to describe these WWTPs. To achieve this design we had two secondary stages. First, we chose the WWTPs levels and technologies mostly used in Antioquia. Second, we described the layout and operational stages of these WWTPs technologies based on previous texts examined.

Although we also used various texts from the environmental research group GAIA to write this guide. GAIA had a group of engineers that worked with Cornare to achieve three goals: first, to start-up various WWTPs in Antioquia. Second, to teach operators in charge of these WWTPs how to measure physicochemical variables. Third, to write guides on these WWTPs. And these engineers wrote various brief texts to describe the operation stage, setbacks and flaws in these WWTPs technologies. These engineers improved the WWTPs in two different ways. First, they showed the proper operational practices. Second, they showed conceptual layouts to improve these WWTPs technologies. Therefore this group helped us write this guide clearly to prevent flaws in the future WWTPs.

Results

Guide

We found that we could prevent flaws in WWTPs in Antioquia by using this guide designed. We could use this brief guide in four different ways. First, as a layout standard to simplify the process to get a WWTPs permit (Langergraber *et al.*, 2018). Second, as a guide for a realistic approach to treat wastewater in WWTPs for students, engineers, and managers. Third, as a handbook to improve the training guides (TGs) for operators in charge of the operational stage of these WWTPs. Fourth, as a handbook to prevent flaws in the future WWTPs.

We described two main topics and subtopics in this guide to prevent flaws. These topics were the layout and operational stages of various WWTPs in Antioquia. These subtopics were the WWTPs levels and technologies mostly used in Antioquia. In this guide, we indicated a few small layouts that professionals could take to be in charge of these WWTPs properly. Therefore we defined this guide as a standard to prevent flaws. This guide is known as "Guía de diseño conceptual y operación de plantas de tratamiento de aguas residuales domésticas en pequeñas comunidades para profesionales".

Here two different ways in which this guide could help us prevent flaws in WWTPs. First, we described the number of flaws in these WWTPs. We indicated hydraulic criteria such as the hydraulic retention times and arranged distribution of packing material. Second, we kept up with the latest layout and operational developments in WWTPs, which improve these TGs for operators with the proper documentation and operational practices.

WWTPs Classification

To prevent flaws we classified these WWTPs into a combination of various levels and technologies. These levels were pre-treatment (P), primary treatment (PT), secondary treatment (ST) and sludge treatment (SludgeT). These levels presence was 16.8 % of the 89 WWTPs used PT with SludgeT, 68.5 % of these WWTPs used PT, ST, and SludgeT (**Fig 2**), 10.1 % of these WWTPs used ST and 86.5 % of these WWTPs used SludgeT. All of these WWTPs used P. None of these WWTPs used tertiary treatment (TT) such as nutrient removal.

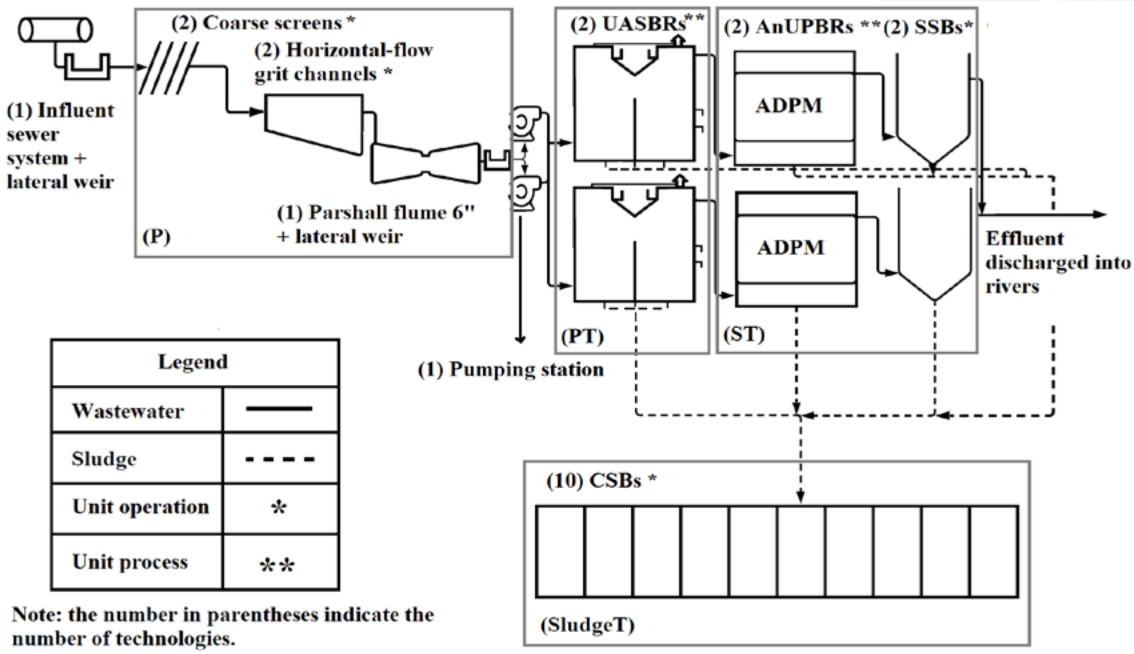


Figure 2. WWTP in San Vicente Ferrer

Note: Own elaboration.

These technologies presence was 86.5 % conventional sand beds (CSBs), 65.2 % upflow anaerobic packed-bed reactors (AnUPBRs), 42.7 % UASB reactors (UASBRs), 28.1 % primary sedimentation basins with inclined plates (PSBs), 24.7 % anaerobic sludge digesters (AnSDs), 16.9 % septic tanks (STs), 7.9 % facultative lagoons (FLs), 6.7 % oxidation lagoons (OLs), 5.6 % anaerobic lagoons (ALs), 4.5 % trickling filters (TFs), 3.4 % anaerobic baffled reactors (AnBRs), and 1.1 % secondary sedimentation basins (SSBs) (**Table 1**).

Table 1. WWTPs levels and technologies in Antioquia

	WWTPs IN ANTIOQUIA	LEVELS → ↓	TECHNOLOGIES												
			P	PT				ST						SludgeT	
			P	PSBs	STs	AnBRs	UASBRs	AnUPBRs	ALs	FLs	OLs	TFs	SSBs	AnSDs	CSBs
1	Abejorral	P,PT,ST,SludgeT													
2	Abriaquí	P,PT,ST,SludgeT													
3	Alejandría (North)	P,PT,ST,SludgeT													
4	Amagá	P,PT,ST,SludgeT													

	WWTPs IN ANTIOQUIA	LEVELS → ↓	TECHNOLOGIES											
			P	PT				ST						SludgeT	
			P	PSBs	STs	AnBRs	UASBRs	AnUPBRs	ALs	FLs	OLs	TFs	SSBs	AnSDs	CSBs
5	Amalfi (Principal)	P,PT,ST,SludgeT	■				■	■							■
6	Andes	P,PT,SludgeT	■	■										■	■
7	Angelópolis 1 (Principal)	P,PT,ST,SludgeT	■				■	■							■
8	Angelópolis 2 (Liceo)	P,PT,ST,SludgeT	■		■			■							■
9	Angelópolis 3 (María Auxiliadora)	P,PT	■		■										
10	Angostura	P,PT,ST,SludgeT	■				■	■							■
11	Santa Fe de Antioquia	P,ST	■						■	■					
12	Anzá	P,PT,SludgeT	■				■								■
13	Arboletes	P,ST	■								■				
14	Argelia	P,PT,ST,SludgeT	■				■	■							■
15	Belmira (Labores)	P,PT,ST,SludgeT	■		■			■							■
16	Betania	P,PT,SludgeT	■	■										■	■
17	Betulia	P,PT,ST,SludgeT	■	■				■						■	■
18	Ciudad Bolívar	P,PT,SludgeT	■	■										■	■
19	Campamento (South)	P,PT,ST,SludgeT	■				■	■							■
20	Caracolí	P,PT,ST,SludgeT	■		■			■							■
21	Caramanta 1 (Principal)	P,PT,ST,SludgeT	■	■				■						■	■
22	Caramanta 2 (San Ignacio)	P,PT,ST,SludgeT	■		■			■							■
23	Caramanta 3 (El Cementerio)	P,PT,ST,SludgeT	■		■			■							■
24	El Carmen de Viboral	P,PT,SludgeT	■	■										■	■
25	Cocorná	P,PT,SludgeT	■	■										■	■
26	Cocorná (La Piñuela)	P,PT,ST,SludgeT	■				■	■							■
27	Concepción	P,ST	■							■					
28	Concordia (Salazar)	P,PT,ST,SludgeT	■	■				■							■

	WWTPs IN ANTIOQUIA	LEVELS → ↓	TECHNOLOGIES												
			P	PT				ST						SludgeT	
			P	PSBs	STs	AnBRs	UASBRs	AnUPBRs	ALs	FLs	OLs	TFs	SSBs	AnSDs	CSBs
29	Copacabana	P,PT,ST	■		■			■							
30	Don Matías	P,PT,ST,SludgeT	■		■			■							■
31	El Bagre	P,PT,ST,SludgeT	■				■	■							■
32	Entrerríos	P,PT,ST,SludgeT	■	■				■						■	■
33	Frontino	P,ST	■						■	■	■				
34	Girardota 1	P,PT,ST,SludgeT	■		■			■							■
35	Girardota 2	P,PT,ST,SludgeT	■		■			■							■
36	Gómez Plata	P,PT,ST,SludgeT	■				■	■							■
37	Granada	P,PT,ST,SludgeT	■	■				■						■	■
38	Guadalupe	P,PT,ST,SludgeT	■				■	■							■
39	Guarne	P,PT,SludgeT	■	■										■	■
40	Guatapé (Betania sector)	P,PT,ST,SludgeT	■	■			■	■						■	■
41	Hispania	P,PT,ST,SludgeT	■	■				■						■	■
42	Jardín	P,PT,SludgeT	■				■							■	■
43	Jericó	P,PT,ST,SludgeT	■				■					■			■
44	La Ceja	P,ST	■						■	■					
45	La Unión	P,PT,SludgeT	■				■								■
46	Maceo	P,PT,ST,SludgeT	■		■			■							■
47	Marinilla	P,PT,SludgeT	■	■										■	■
48	Montebello (Principal)	P,PT,ST,SludgeT	■	■				■						■	■
49	Montebello (Sabaletas)	P,PT,ST,SludgeT	■	■				■							■
50	Montebello (Zarcitos)	P,PT,ST,SludgeT	■	■				■							■
51	Nariño	P,PT,SludgeT	■				■								■
52	Necoclí	P,ST	■								■				
53	Olaya (Llanadas)	P,PT,ST,SludgeT	■				■	■							■
54	Peñol 1 (Principal)	P,PT,ST,SludgeT	■	■				■						■	■
55	Peñol 2 (Florito Cenito)	P,PT,ST,SludgeT	■		■			■							■
56	Pueblorrico	P,PT,ST,SludgeT	■	■				■						■	■

WWTPs IN ANTIOQUIA		LEVELS → ↓	TECHNOLOGIES												
			P	PT				ST						SludgeT	
			P	PSBs	STs	AnBRs	UASBRs	AnUPBRs	ALs	FLs	OLs	TFs	SSBs	AnSDs	CSBs
57	Puerto Berrío	P,ST	■						■	■					
58	Puerto Nare	P,PT,ST,SludgeT	■				■	■							■
59	Puerto Triunfo	P,PT,ST,SludgeT	■	■							■			■	■
60	San Carlos	P,PT,SludgeT	■	■										■	■
61	San Francisco (Principal)	P,PT,ST,SludgeT	■				■	■							■
62	San Francisco (Cascajo)	P,PT,SludgeT	■	■										■	■
63	San Francisco (Aquitania 1)	P,PT,ST,SludgeT	■			■		■							■
64	San Francisco (Aquitania 2)	P,PT,ST,SludgeT	■		■			■							■
65	San José de la Montaña	P,PT,ST,SludgeT	■				■	■							■
66	San Juan de Urabá	P,PT	■				■								
67	San Luis	P,PT,SludgeT	■				■								■
68	San Luis (Buenos Aires)	P,PT,ST,SludgeT	■		■			■							■
69	San Luis (El Prodigio)	P,PT,ST,SludgeT	■				■	■							■
70	San Pedro de Los Milagros	P,PT,ST,SludgeT	■				■	■							■
71	San Pedro de Urabá	P,ST	■							■	■				
72	San Roque	P,PT,SludgeT	■				■								■
73	San Vicente Ferrer	P,PT,ST,SludgeT	■				■	■					■		■
74	Santa Bárbara (Damasco)	P,PT,ST,SludgeT	■	■				■							■
75	Santa Rosa de Osos	P,PT,ST,SludgeT	■				■	■							■
76	Santo Domingo (Principal)	P,PT,ST,SludgeT	■				■	■							■
77	Santo Domingo (Santiago)	P,PT,ST,SludgeT	■		■			■							■
78	El Santuario	P,PT,ST,SludgeT	■	■				■						■	■

	WWTPs IN ANTIOQUIA	LEVELS → ↓	TECHNOLOGIES												
			P	PT				ST						SludgeT	
			P	PSBs	STs	AnBRs	UASBRs	AnUPBRs	ALs	FLs	OLs	TFs	SSBs	AnSDs	CSBs
79	Sonsón	P,PT,ST,SludgeT													
80	Sopetrán (Horizontes)	P,PT,ST,SludgeT													
81	Támesis	P,PT,ST,SludgeT													
82	Tarso	P,PT,ST,SludgeT													
83	Titiribí (Eastern)	P,PT,ST,SludgeT													
84	Titiribí (Western)	P,PT,ST,SludgeT													
85	Turbo	P,ST													
86	Valparaíso	P,PT,ST,SludgeT													
87	Venecia	P,PT,ST,SludgeT													
88	Yalí (North)	P,PT,ST,SludgeT													
89	Yalí (South)	P,PT,ST,SludgeT													

Note: that Corpouraba (2019), Corantioquia (2019b) and Cornare (2019) shared with us this data base of various WWTPs in Antioquia.

We used a variation of black color to show these WWTPs technologies used in various municipalities of Antioquia. This variation of black showed that these WWTPs used mostly pre-treatments, conventional sands beds, anaerobic packed-bed reactors, UASB reactors and primary sedimentation basins.

WWTPs levels, technologies, flaws and operational setbacks

Here we described these WWTPs levels and technologies in Antioquia. First, the pre-treatment used coarse bars to remove large solids that can damage pumps, valves and pipes. In this bars, wastewater should have a proper range of velocity. This range is in 0.6 to 0.9 m/s (Qasim & Zhu, 2018). This pre-treatment used horizontal-flow grit channels to remove grits, dense and abrasive material. These channels were rectangular. In these channels, wastewater should have a proper range of velocity. This range is in 0.25 to 0.4 m/s to prevent the sedimentation of organic matter (Qasim & Zhu, 2018). This pre-treatment also used the pumping stations to carry wastewater to a proper elevation to achieve flow by gravity through the WWTPs. These stations were after bars and grit channels. In summary, this pre-treatment had the lack of safe handrails and enter infrastructure for these operators.

Although this pre-treatment had various operational setbacks. These setbacks were the sedimentation of grit and organic matter in these pumping stations and the sedimentation of organic matter in these horizontal-flow grit channels. To prevent these setbacks operators often cleaned these bars and channels. But these operators disposed inappropriately these large solids and grits. This pre-treatment also used a combination of various weirs or Parshall flume to measure the wastewater flow. These weirs were proportional, lateral, rectangular or triangular. This proportional and Parshall flume also regulate the flow velocity in these bars and grit channels.

Second, the primary treatment used primary sedimentation basins with inclined plates to remove settleable organic solids. These sedimentation basins in these WWTPs were mostly rectangular. This primary treatment also used a combination of UASB reactors, septic tanks and anaerobic baffled reactors to remove settleable solids, floated solids and organic matter. Although this primary treatment had various operational setbacks. These setbacks were the small production of biogas in these UASB reactors because of diluted wastewater and the excessive floated solids in these primary sedimentation basins. To prevent these setbacks operators often cleaned these floated solids. But these operators did not test the alkalinity and pH frequently in these UASB reactors and anaerobic baffled reactors.

Third, the secondary treatment used a combination of upflow anaerobic packed-bed reactors, anaerobic lagoons, facultative lagoons, oxidation lagoons, and trickling filters to remove soluble organics that this primary treatment does not remove. These WWTPs seldom used anaerobic lagoons. This secondary treatment also used secondary sedimentation basins to remove suspended solids of final effluent. Although this secondary treatment had various operational setbacks. One of these setbacks was the rotten odors in these upflow anaerobic packed-bed reactors.

Fourth, the sludge treatment used a combination of anaerobic sludge digesters and conventional sand beds. These anaerobic sludge digesters digest the settled solids from primary sedimentation basins. These conventional sand beds dry the sludge from UASB reactors, septic tanks, anaerobic baffled reactors, upflow anaerobic packed-bed reactors, secondary sedimentation basins and anaerobic sludge digesters. These conventional sand beds in these WWTPs had the lack of proper size to dry sludge ideally (Alzate Leal, 2021). Although this sludge treatment had various operational setbacks. These setbacks were the rotten odors and mosquito growth in these sand beds and the excessive solids production in these anaerobic sludge digesters. To prevent these setbacks in these sand beds operators often used lime.

In summary, we found that these WWTPs had two significant percentages. First, 93.3 % of these 89 WWTPs served a population of less than 30.000 (Departamento Administrativo Nacional de Estadística, 2020). Second, 95.5 % of these 89 WWTPs used anaerobic technologies. And these WWTPs mostly used a combination of UASB reactors and upflow anaerobic packed-bed reactors. Others WWTPs used a combination of primary sedimentation basins and anaerobic sludge digesters.

We found that these upflow anaerobic packed-bed reactors post-UASBRs had two main layout flaws in various WWTPs in Antioquia. These flaws were the low hydraulic retention times (HRT) and disordered distribution of packing material (DDPM). Disordered distribution meant the lack of proper limits for a sedimentation basin at the top and for an empty part at the bottom of these upflow anaerobic packed-bed reactors. And these flaws put the layout stage in packed-bed reactors at significant risk in two different ways. First, we discovered engineers designed these packed-bed reactors with one-hour HRT. These engineers should design these packed-bed reactors with four-hours HRT (Von Sperling & Chernicharo, 2005a). Second, we discovered these engineers designed these packed-bed with DDPM, which put a higher risk of material obstructions and operational setbacks.

We found that these layout flaws put the removal efficiency in these upflow anaerobic packed-bed reactors at significant risk. These flaws decreased the removal of organic matter in various WWTPs. These WWTPs were in Abejorral, Argelia, Sonsón, San Francisco, and San Pedro. However, we found the proper HRT and arranged distribution of packing material (ADPM) in WWTP in San Vicente Ferrer (**Fig 3**). We showed these upflow anaerobic packed-bed reactors in the white box of this figure.

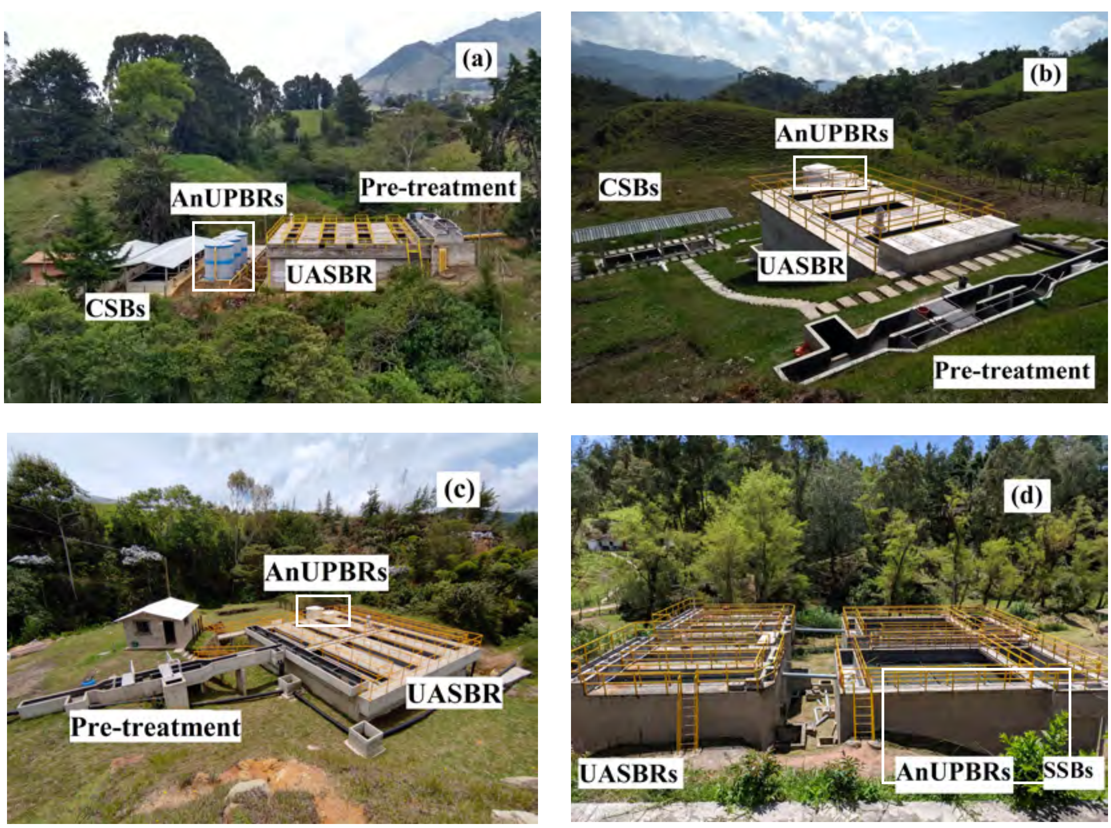


Figure 3. AnUPBRs post-UASBRs of various WWTPs in Antioquia

Note: (a) The WWTP in Sonsón. (b) The WWTP in Argelia. (c) The WWTP in Abejorral. (d) The WWTP in San Vicente Ferrer.

Discussions

We suggest that we could prevent flaws in WWTPs by using this guide designed. Also we could use this guide to improve these TGs for operators in charge of these WWTPs, which makes the operations more efficient. We explained this improvement of these operations because we described these TGs and training courses (TCs) for operators based on the proper operational practices. Because these operators have limited time available, these TCs are brief and intensive. We suggest that these operators have four to six months to complete these TCs in these WWTPs.

These results show that these WWTPs in Antioquia mostly use anaerobic technologies. Surprisingly, this WWTPs technologies presence is 30.3 % of upflow anaerobic packed-bed reactors post-UASB reactors. And 12.3 % of these WWTPs have layout flaws in these packed-bed reactors connected to the low HRT. Therefore these WWTPs with flaws in packed-bed reactors put the wastewater process at significant risk. A possible explanation for these WWTPs with flaws in packed-bed reactors is the lack of proper HRT (Rendón Arango, 2021). These WWTPs have various anaerobic packed-bed reactors post-UASB reactors with one-hour HRT. Although as being noted in the literature, packed-bed reactors have the HRT in the range of four to ten hours. This range of HRT is essential in packed-bed reactors for the transformation of the complex into simple organic matter (Von Sperling & Chernicharo, 2005a; Metcalf & Eddy, 2014; Qasim & Zhu, 2018; Chernicharo & Bressani-Ribeiro, 2019).

These WWTPs have various setbacks in these packed-bed reactors and UASB reactors. These setbacks are the unequal distribution of influent and effluent collection, which increases the preferential ways. These UASB reactors have unsuitable materials for valves, tubes, weirs, and the lack of safe handrails and enter infrastructure for operators. These WWTPs with setbacks help us understand the low efficiency of these packed-bed reactors and UASB reactors.

In summary, we can use this brief guide as a standard to prevent the low efficiency of the future packed-bed reactors. The findings of this research not only provide a handbook to prevent flaws in packed-bed reactors post-UASB reactors, but they also describe various WWTPs technologies used in Antioquia. These findings of this research are also a contribution to get a full picture of these WWTPs levels and technologies to the academic, public and private sectors.

We suggest that the future WWTPs in Antioquia use UASB reactors for two main reasons. First, these UASB reactors remove organic matter. Second, these UASB reactors have lower sludge production than primary sedimentation basins. This production of UASB reactors is in the range of 12 to 18 gSS/inhabitant·d. Although these sedimentation basins require anaerobic sludge digesters to digest settled solids. After this digestion, this production of sedimentation basins is in the range of 25 to 28 gSS/inhabitant·d (Von Sperling & Chernicharo, 2005b).

In future research, it is possible to use a different method in which this full picture of these WWTPs in Antioquia changes when the technologies are classified by flow capacity. In future research, it is also possible to study the use of aerobic post-anaerobic technologies in the future WWTPs in Antioquia. These technologies could be trickling filters and secondary sedimentation basins post-UASB reactors to connect anaerobic and aerobic functions (Chernicharo, 2006; De Almeida *et al.*, 2009; Bressani-Ribeiro *et al.*, 2018).

Torres-Lozada *et al.* (2016) stated that WWTPs technologies mostly used in Cali (Colombia) are these trickling filters and secondary sedimentation basins post-UASB reactors. These filters remove significant percentages of solids and organic matter. These percentages are in the range of 80 to 85 %. Further research, it might describe the advanced technologies used in urban areas to academics who want to know about these WWTPs in Antioquia.

Conclusions

We conclude that we could prevent flaws in the future WWTPs by using this guide designed. Also we could use this guide to improve the training guides and courses for operators in charge of these WWTPs.

We conclude that these WWTPs in Antioquia mostly use anaerobic technologies. These WWTPs technologies require to operate properly to prevent operational setbacks because these setbacks decreased the removal efficiency of organic matter.

We conclude that these existing WWTPs in Antioquia mostly use manually cleaned pre-treatments. One of these pre-treatments is horizontal-flow grit channels. And various operators often clean these channels to prevent setbacks. One of these setbacks is the sedimentation of organic matter.

We also conclude that these existing WWTPs in Antioquia use two main anaerobic technologies. These technologies are upflow anaerobic packed-bed reactors and UASB reactors. These packed-bed reactors have one main layout flaw. This flaw is the low hydraulic retention times. And these UASB reactors have unsuitable materials for valves, tubes and weirs.

We conclude that these existing WWTPs in Antioquia have various flaws. These flaws are the inappropriate localization, the lack of proper size in these conventional sands beds and the lack of safe handrails and enter infrastructure for operators.

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