DESIGN OF THE INTERCEPTOR-COLLECTOR AND WASTEWATER TREATMENT SYSTEM FOR POLLUTION MITIGATION: A CASE STUDY

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ABSTRACT

Sustainable Development Goal 6 proposes clean water and sanitation for all. Urban parishes Veintimilla and Polibio Chávez of the Guaranda canton in Ecuador have a combined sewage network. However, they do not have an operational wastewater treatment plant (WTP), which discharges directly into the river generating significant pollution and affecting the health and well-being of the inhabitants. This work aims to design the interceptor-collector and treatment system for wastewater discharges to the Guaranda river, considering the technical aspects and sustainability criteria, contributing to the quality of life of its inhabitants, the mitigation of pollution, and the compliance with current regulations. The methodology used was: (i) review and analysis of existing information, which included topographical, social, economic, technical, and environmental restrictions; (ii) proposal and selection of alternatives; (iii) design of the selected alternative, with its respective budget, plans, and environmental analysis. The results were: (i) design errors in the existing system, industrial discharges contaminate domestic wastewater; (ii) alternatives were proposed that were assessed using the Likert scale, with number A1b being the winner; (iii) the estimated future population is 32,922 inhabitants, and the design period is 15 years, which generates a flow of 0.226 m^3/s. The interceptor-collector consists of four bypass chambers; the WTP consists of two independent lines, each with preliminary treatment, a sand trap of 17.25 × 3.85 × 1.15 m, and percolating filters 15.4 × 7 × 2.4 m, and a clarifier of 15.4 m by 3.5 m in height. The budget is USD 941,953.49, including the environmental management plan.

Keywords: sustainability, pollution, sewage, percolating filters, wastewater treatment plant (WTP).

1 INTRODUCTION

Wastewater is defined as water that has been polluted due to human activities. These waters can be raw (grey or black) and can potentially cause significant damage to human and environmental health [1]. However, its use as a reliable and cost-effective pre-treated water source, particularly for agricultural or industrial applications, is increasingly recognised [2].

Water is the source most affected by population growth, so the need for effluent treatment has become a significant concern [3], [4]. However, the high costs of wastewater purification make it challenging to implement treatment plants, mainly due to the long distances that the effluent must be transported (often requiring pumping stations to reach the treatment area) [5]. Furthermore, the lack of low-cost and straightforward management technologies makes it impossible to use them in rural areas and communities with low population density. Due to this, research has been developed to optimise the effluent purification processes [6]–[8]. In a context like a case addressed in this study, an example was carried out in the Montañita community, Ecuador. Specifically, the application of a pilot plan for green filters to reduce the pollutants concentrations in wastewater [9]. This natural purification technique saves

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operating costs and makes it possible to contribute to reforestation with endemic trees, promoting the circular economy.

In general, many urban areas lack preventive systems against pollution by domestic wastewater [10], [11]. Globally, inadequate sanitation-wastewater treatment systems and a lack of reusable water affect small towns and rural communities [12]. As a result, 82% of the rural population in developing countries lack basic sanitation [13].

Ecuador is not a country alien to this problem. The National Water Secretariat (SENAGUA) revealed that approximately 20% of domestic wastewater is treated in the country. The rest is discharged directly into rivers and streams. As a result, 48.5% of the rural population has safe drinking water, and 86.3% has basic sanitation [14].

Guaranda city is part of the Ecuadorian highlands; being the capital of Bolivar province, it is positioned at an average elevation of 2,668 m.a.s.l. (meters above sea level). It is composed of three urban parishes. This city has a sewage system that began to be built in the 1960s and 1970s, which discharged directly into the Guaranda River. In 2001, a treatment plant was inaugurated to which the discharges from the Ignacio Veintimilla and Polibio Chávez parishes were conducted through an outfall collector. This was a participatory action between the municipality and small communities, which is very common in Ecuador [15]. Due to problems in its design, the collector collapsed due to the intense rains in this area, returning to the previous system (direct discharge to the river) [16].

This research aims to design the interceptor and treatment system for wastewater discharges from the Ignacio Veintimilla and Polibio Chávez parishes in Guaranda. In addition, consider the treatment system's technical aspects and sustainability criteria to guarantee water pollution mitigation and compliance with current regulations.

2 STUDY AREA

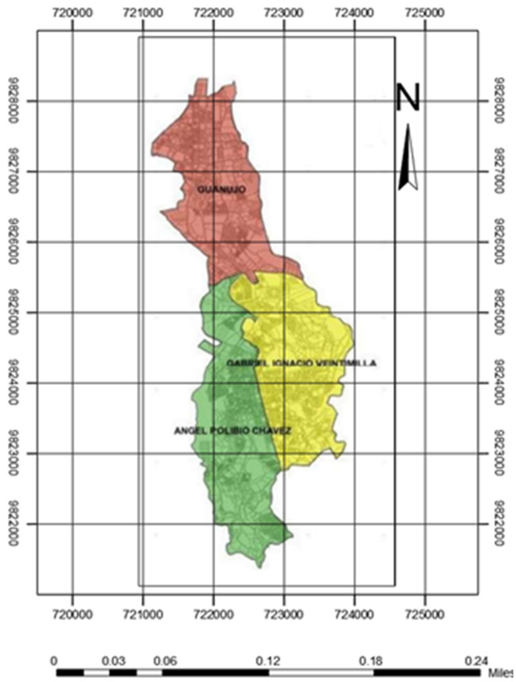
Guaranda city is the capital of the Bolivar province, located 220 km from Quito (Ecuador's capital) and 150 km from Guayaquil (the country's principal port). According to the National Statistics and Census Institute (INEC) [17], its population is 55,374 inhabitants. Guaranda is made up of three urban parishes: Guanujo, Ignacio Veintimilla and Polibio Chávez (see Fig. 1(a)). According to the National Meteorology and Hydrology Institute (INAMHI) [18], it has an average temperature of 13°C.

90% of Guaranda's urban population receives drinking water from the Municipal Potable Water and Sewage Company (EMAPA-G). However, the urban periphery and the rural area do not have drinking water services. Also, according to INEC [17], 31% of the population has a sewerage network connection, and another 31% uses a septic tank. Currently, no area of the city of Guaranda has wastewater treatment plants in operation.

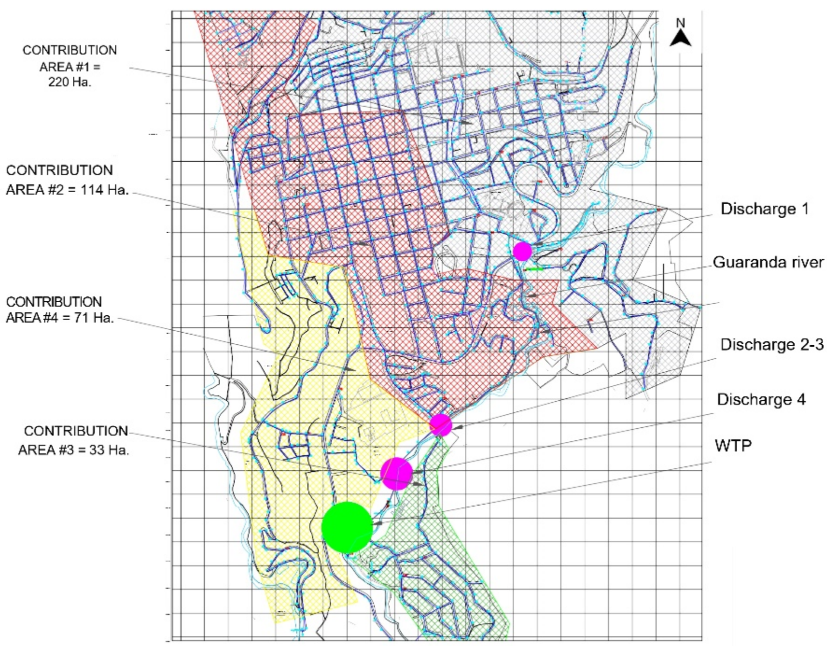
There are some contribution zones corresponding to the Veintimilla and Polibio Chávez parishes. Wastewater is collected through household connections and rainwater through sinks in each area. The primary collectors lead these to the discharge points on the Guaranda River (see Fig. 1(b)).

3 MATERIALS AND METHODS

For the development of this research, three phases are proposed that include: (i) review and analysis of existing information, which includes topographical, social, economic, technical, and environmental restrictions; (ii) proposal and selection of alternatives; (iii) design of the selected alternative, with its respective budget, and environmental analysis (see Fig. 2).



(a)



(b)

Figure 1: (a) The geographical location of Guaranda city and its urban parishes; and (b) Wastewater and rainwater discharge points [16], [19].

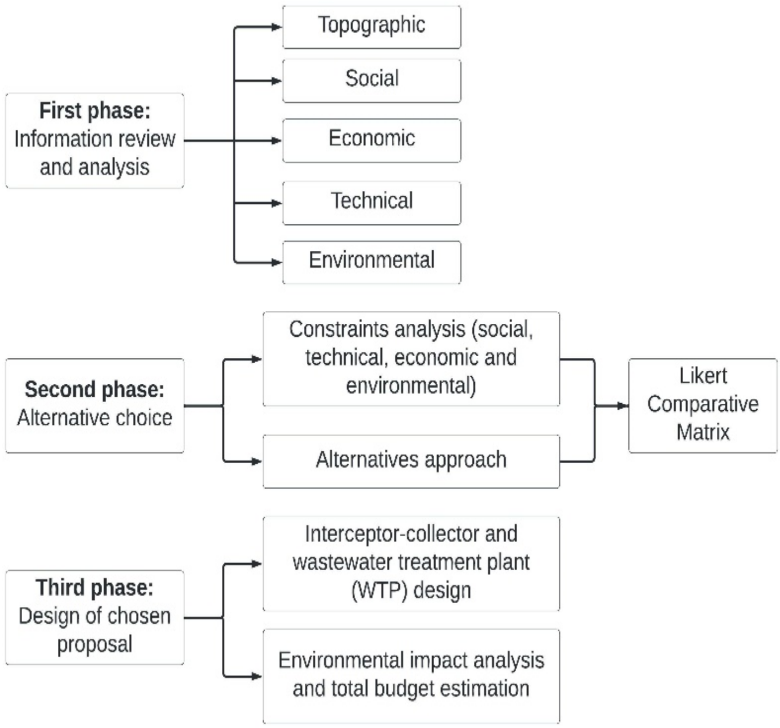


Figure 2: The methodological research map.

3.1 First phase: information review and analysis

The investigation begins with the information collected from the study area, including topographical, social, economic, technical, and environmental data. Data processing involves analysing and comparing existing information. In addition, a technical visit was made to the study area with EMAPA-G personnel, where they also provided files about the sewerage and drinking water master plan of the Guaranda canton.

The data collected in this phase are the basis for designing the wastewater collection, transport, and treatment system according to the study area with optimal operability.

3.2 Second phase: Alternative choice

In this phase, the analysis of the study area's economic, environmental, social, and technical restrictions was carried out.

In the economic analysis, from meetings with EMAPA-G, a system with low operation and maintenance costs (OPEX) is desired. In addition, a system that works by gravity and with this avoids energy expenses for pumping.

The environmental analysis considered whether the project would be in an area considered to be protected by forests or fauna, decreed by the Ministry of the Environment, Water and Ecological Transition (MAATE). Furthermore, it is required to make the most negligible environmental impact as far as possible. Therefore, laboratory tests were carried out on the discharge waters of Guaranda city (see Fig. 1). These were compared to national regulations such as the Unified Text of Secondary Environmental Legislation (TULSMA, its acronym in Spanish) and the Ecuadorian Practice Code [20].

In the social analysis, the surrounding community was considered since there is a possibility of generating bad odours and pests (e.g., mosquitoes in winter). Furthermore, depending on the final effluent quality, its use in agricultural areas in surrounding areas was also analysed.

The technical analysis analysed the territorial availability of the treatment system and the topography. Population growth was calculated for the design period. The population growth projection was carried out using three different methods (arithmetic, geometric and exponential) following the regulations with starting data taken from the censuses carried out by INEC [17].

Once the restrictions were analysed, alternatives were proposed for the interceptor and the purifying system for the study area. The Likert assessment method was used, for which it is taken from 1 for "very unfavourable" to 5 for "very favourable". The one with the highest score was selected as the most convenient or optimal.

3.3 Third phase: Design of the chosen proposal (interceptor-collector + purifying system)

The design of the interceptor-collector system was based on three main criteria: (i) consideration of the natural slope of the terrain prioritising transport by gravity, (ii) design of chambers with the necessary dimensions to contain wastewater and rainwater so that, autonomously, excess rainwater is diverted to the Guaranda river, and (iii) the water from the interceptor is directed to the wastewater treatment plant (WTP). In addition, the design considers the current regulations of the country and the conditions of the study area. The design period was projected at 15 years for the selected alternative to effectively comply with the transport of wastewater and minimise its implementation costs.

WTP design must comply with the maximum permissible limits (MPL) for treated effluents, stipulated in the current Ecuadorian regulations (TULSMA-2015 Book VI Annex 1 Table 10). Therefore, a pre-treatment system was designed that removes coarse material and prevents the accumulation of sand and grease that could compromise subsequent treatment. Additionally, installing a purification system based on a percolator filter and a clarifier is proposed. The main objective is the disinfection of wastewater, notably eliminating the organic load (see Fig. 3).

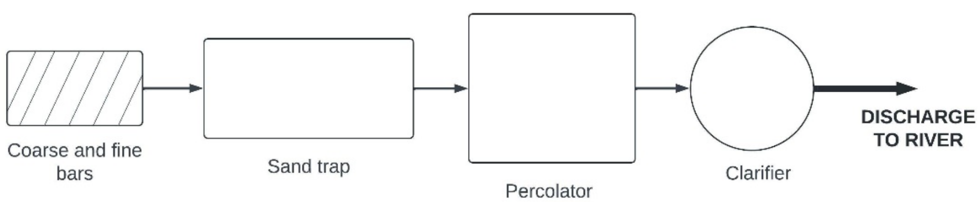


Figure 3: Scheme of the treatment system proposed.

In addition, the environmental impact assessment was carried out for the proposed design in the study area. This evaluation was carried out using the integrated relevant criteria (IRC) methodology proposed by Buroz [21]. It consists of assigning a numerical value to each impact based on indicators that make up the environmental impact value index (EIVI).

4 RESULTS

4.1 Population growth projection

In the last census carried out by the INEC in 2010, the population registered in the urban parishes of Polibio Chávez, and Gabriel Ignacio Veintimilla was 23,874 inhabitants. According to the CPE-INEN standard, the design period for a population such as Guaranda must be 15 years. Table 1 shows the projections for 2021, 2026, 2031 and 2036. In Fig. 4, it can see the results until the year 2036 (with the R^2 factor), so the projection was chosen by the arithmetic method because it has a factor $R^2 = 1$.

Table 1: Population projections of the Ignacio Veintimilla and Polibio Chávez parishes.

Year	Arithmetical method	Geometric method	Exponential method
2021	27,702	28,351	29,875
2026	29,442	30,655	33,081
2031	31,182	33,146	36,630
2036	32,922	35,840	40,561

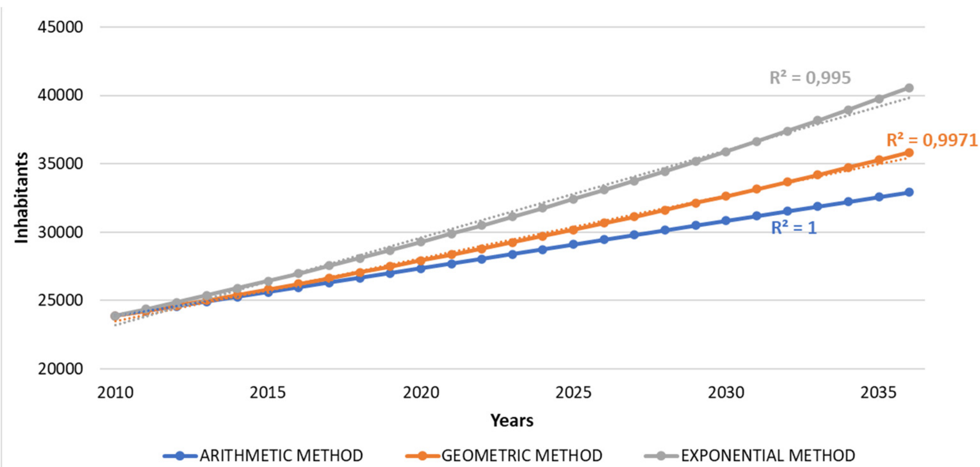


Figure 4: Population projection with its respective R^2 factor.

Also, for the population growth projection choice, the page of the Decentralized Autonomous Government of Guaranda (GAD-Guaranda, acronym in Spanish) was reviewed [22]. It indicates that the population, in 2021, was 25,000. Therefore, the population projection by the arithmetic method would be the closest, according to data from the GAD-Guaranda.

4.2 Laboratory results

The laboratory tests of residual water were carried out at four discharge points. These results were compared with the MPL of the TULSMA. Table 2 shows the main results, underlining the parameters that exceed the TULSMA limits in red.

Table 2: Laboratory tests carried out on each wastewater discharge

Parameter	Unit	TULSMA limits	Vivero discharge	Marcopamba discharge	Negroyaco discharge	Vinchoa bridge discharge
COD	mg/L	200	543.08	465.28	210.67	740.06
BOD_5	mg/L	100	249.61	257.38	97.68	371.62
E. Coli	Col/L	2,000	2600	2,200	800	3,400
Total phosphorous	mg/L	10	12.70	12.83	9.87	16.47
Total iron	mg/L	10	11.01	14.75	10.02	15.68
Total manganese	mg/L	2	2.93	3.97	2.13	4.07
Total nitrogen	mg/L	50	61.67	52.97	50.69	55.46
Total suspended solids (TSS)	mg/L	130	120.07	135.34	110.46	172.39
Tensides	mg/L	0.5	3.64	2.60	1.97	8.94

4.3 Alternative choice

4.3.1 Alternatives proposal

The proposed alternatives in this research are:

1. Alternative 1: Design the interceptor that connects all the discharges with the existing plant, redesign the existing reactors and implement the necessary ones to carry out a purification with the following systems:
   a. Treatment line 1: Anaerobic, physical-chemical process and filter
   b. Treatment line 2: Percolating filter and clarifier
2. Alternative 2: Design two interceptors that connect the discharges in two groups, directing group 1 to a new plant and group 2 to the area of the existing plant using the following systems:
   a. Treatment line 1: Anaerobic, physical-chemical process and filter
   b. Treatment line 2: Percolating filter and clarifier

4.3.2 Likert comparative matrix

Table 3 shows the evaluation results in the Likert matrix of the alternatives proposed in 4.3.1. Once all the alternatives have been evaluated, the one with the highest score is selected as the most convenient.

With a result of 65 points, the selected alternative is A1b. This alternative corresponds to the interceptor's design that connects all discharges with the existing plant. Therefore, the present reactors were redesigned, and the necessary ones were implemented to carry out a purification with percolating filter and clarifier.

4.4 Interceptor-collector design

The interceptor-collector design consists of pipes plus four chambers placed in each of the identified discharges (see Fig. 1). As it is a single collector, which transports urban

Table 3: Selection of the optimal alternative using the Likert matrix.

	Alternative 1 (A1)		Alternative 2 (A2)	
	A1a	A1b	A2a	A2b
EMAPA-G preferences				
Design uses existing floor area	5	5	5	5
Design uses existing reactors	5	5	5	5
Economic Considerations				
No new land acquisition required	5	5	2	2
The design does not require earthwork	5	5	2	2
Topographical studies	4	4	3	3
Energy costs	3	3	2	2
Chemical consumption costs	2	5	2	5
Requires trained staff	3	3	3	3
Sludge management	2	3	2	3
Social considerations				
Pest presence	5	5	5	5
Generates bad odours	5	5	5	5
Technical considerations				
Contaminant removal above the required	5	4	5	4
Gravity designed	5	5	5	5
Environmental considerations				
Eutrophication risk in the receiving body or other aquifers	5	5	5	5
Damage to flora and fauna	3	3	2	2
TOTAL	62	**65**	53	56

wastewater and rainwater, the necessary dimensions must be able to control both flow types. Therefore, the interceptor directs only the wastewater and rainwater flow (10%) to the WTP. The rest of the rainwater flow must be diverted autonomously by the chambers, directly to the Guaranda river.

Four interceptor-collector chambers were designed, considering the following: (i) minimum capacity (allows personnel to enter for cleaning and maintenance), and (ii) speed and minimum diameter (time to avoid sedimentation). Table 4 shows the dimensions, flow to the interceptor-collector and the river, diameter, and velocity of the outlet pipe.

As an example of a design scheme, chamber 1 is observed in Fig. 5.

Table 4: Dimensions of the proposed chambers.

Parameters	**Chamber 1**	**Chambers 2 & 3**	**Chamber 4**
Volume (length × width × height) (m^3)	2.69 (1.8 × 1.8 × 0.83)	3.61 (1.9 × 1.9 × 1.0)	3.30 (1.8 × 1.8 × 1.02)
Outlet pipe diameter (m)	0.60	0.70	0.70
Output speed (m/s)	1.25	1.98	2.08
Input flow (m^3/s)	2.67	3.47	1.04
Output flow (m^3/s)	0.36	0.76	0.81
Flow to the river (m^3/s)	2.31	2.71	0.23

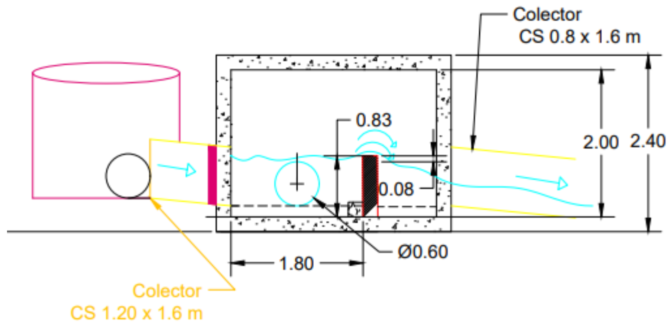


Figure 5: Scheme of interceptor-collector chamber 1.

4.5 WTP design

First, WTP regulation tank is designed. The regulation tank must store the flow derived by the chambers. Then, the stored water must be released to the WTP through an outlet pipe with a stop valve. The outlet pipe must be designed so that the flow rate does not exceed 20% of the WTP design flow rate. Therefore, to comply with this, the regulation tank sizing, the emptying pipe, and the pipe for sludge removal are carried out. Fig. 6 shows a scheme of the regulator tank.

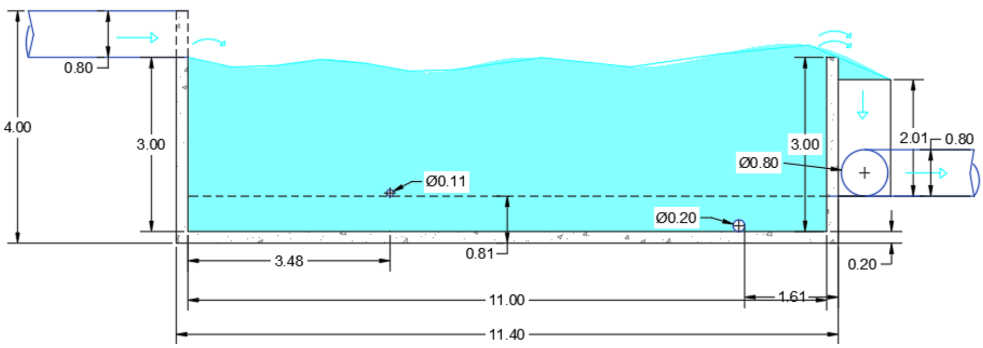


Figure 6: Cross-section of the regulator tank.

As a second part of the WTP, the preliminary treatment design is used to remove larger solids (plastic containers, bottles, branches, among others). For this, thick and thin bars were designed. For thick bars, 1 cm thick and with a separation of 2.50 cm between them are proposed. At the same time, fine bars are proposed with a thickness of 0.50 cm and a separation of 1.00 cm. After passing through the thick and fine bars, we proceed to the sand trap. The sand trap is a unitary operation that removes the sedimentable solids present in the raw wastewater. This is due to its length and hydraulic retention time.

The following system to design is a percolator filter. This filter is designed to obtain an effluent with a BOD_5 maximum of 80 mg/L. This level is below the BOD_5 maximum permissible limit of 100 mg/L for discharges to freshwater bodies given by the TULSMA. Furthermore, the contaminant load, which enters the filters (see Table 3), are results obtained in the EMAPA-G laboratory. Therefore, a percolating filter with a volume of 163.80 m^3 with a height of 1.50 m is proposed. Fig. 7 shows a scheme of the percolator filter proposed for the WTP.

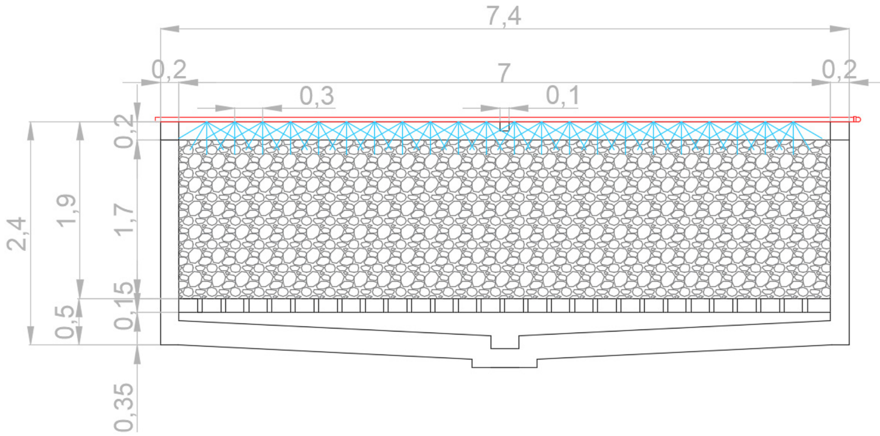


Figure 7: Cross-section of the percolator filter.

Lastly, a clarifier is required in WTP, prior to discharge to the receiving body to eliminate suspended sedimentable particles generated from the previous process.

With this WTP, it is possible to reduce the contaminants present in the wastewater, especially by 79% of the initial value of BOD_5. As a result, a value of 64 mg/L of BOD_5 is obtained in the final purified water.

4.6 Environmental impact and budget

The environmental aspects that will be affected by the execution of the project were identified through the analysis of the physical, biotic, and socioeconomic aspects, identifying that in each of them, there will be impacts in small proportions. The activities that are considered to have a high impact are: (i) the exploitation and transportation of imported borrow material (dust emission and soil contamination), and (ii) excavation and removal of material (soil contamination).

Lastly, an approximate evaluation of the budget of all the proposed designs has been made. The budget has been divided into two parts, one for the interceptor-collector chambers and another for the WTP. For the cameras, there is a budget of USD 554,946.61, while the WTP budget is USD 387,006.88. WTP cost is lower because old WTP tanks have been considered.

5 CONCLUSIONS

Guaranda, Ecuador, is a typical example of a city without a land-use plan that needs a wastewater treatment system. Alternatives with viable solutions for the problem were proposed considering the existing systems, restrictions, and favourable factors. The chosen design considers the transport and treatment of wastewater by the country's current regulations. The system promotes the health and well-being of the inhabitants and prevents Guaranda river contamination. Total removal levels achieved are less than 80 mg/L of BOD_5.

Alternative A1b was selected, which consists of designing an interceptor, four chambers and a Wastewater Treatment Plant (WTP) with two treatment lines. Each line is made up of the pre-treatment that consists of roughing and sand trap, a series of percolator filters and a clarifier. In addition, the use of the existing plant facilities is proposed.

The interceptor was designed to collect residual water and a percentage of rainwater (first washing water) through the sewage network towards the WTP. As a result, the purification system reduces the contaminants present in the wastewater by 79%, discharging the purified effluent to the receiving body with a BOD_5 value of 64 mg/L, complying with the discharge limits to a body of freshwater exposed in the TULSMA.

Environmental analysis and an estimated budget of the selected alternative were carried out. The transportation, exploitation and placement of loan material was the activity with the highest environmental impact. The budget, including the interceptor-collector and the WTP, reaches USD 941,953.49. For a design population of 32,922 inhabitants, the cost is USD 28.61 per inhabitant. This value is low because it should be considered that it is only about the interceptor and the purifying system; it does not include secondary, tertiary or home networks.

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