DESIGN OF A SEWAGE AND WASTEWATER TREATMENT SYSTEM FOR POLLUTION MITIGATION IN EL ROSARIO, EL EMPALME, ECUADOR

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ABSTRACT

Water sanitation is one of the biggest challenges nowadays. The sixth sustainable development goal of the 2030 agenda of the United Nations focuses on the importance of clean water and sanitation worldwide. El Rosario parish (Ecuador) was founded in 1991 and has never had a sanitary sewer system and a wastewater treatment system since. The households of the 47 hectares directly discharge domestic wastewater to a stream which flows into Daule river. This river is the primary source of drinking water for more than 4 million people that live in the province of Guayas. It implies problems with health, hygiene, and significant environmental impacts. This paper aims to develop a technical proposal for the design of sewerage and wastewater treatment, through technical analysis of the area of study, mitigating environmental and health impacts. The methodological process includes: (i) acquiring relevant data like current population, information related to the drinking water system and water supply, topography, weather, and water resources; (ii) layout of primary, secondary, and tertiary branches of the sanitary sewage system; (iii) calculation of the direction of nearby water resources' drainage that lead the layout of primary and secondary branches of the storm sewage system; and (iv) analysis for the selection of the wastewater treatment system, capacity, location, and design. As a result, this work proposes the design of stabilization ponds implanted in 14.2 ha with 26 km of sanitary and storm sewer networks in a separative sewage system. In addition, the execution of the proposal is estimated for 9.5 months for a value of approximately USD 2,157,100.35. This solution will mitigate the pollution of the Daule river and improve the life quality of the inhabitants of the rural community.
Keywords: sewage, wastewater treatment system, water quality, sanitation, environmental impact.

1 INTRODUCTION

Water is a main natural resource which requires a previous treatment before its use by humans. However, water needs a treatment after its use and prior its discharge to water bodies [1]. In general, domestic wastewater could be of two types: grey water and black water. Grey water refers to wastewaters from kitchens, sinks and showers. Black water includes wastewaters from toilets. It is important to be able to distinguish the types of wastewater for its appropriate treatment and subsequent reuse [2]. To take advantage of the water resource and preserve it, it is governments' duty to build waterworks like sanitation and depuration systems [3] (e.g. water volumen, surface characteristic of the terrain, hydrogeology).

The magnitude growth of human activities generates a negative impact on the environment [4]. This impact includes big amounts of wastewater that end into water bodies around the world [5]. In general, wastewaters are treated but in some cases the appropriate measurments are not followed. This situation is more common in commuties with low income, like rural zones. In this kind of zones, water bodies like streams are turned into sewerage systems and garbage dumps turning these places into main disease spread points

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[6]. An ideal situation is a sewerage system which recolects and transports wastewater to a treatment plant before its discharge.

The absence of a sewage and wastewater treatment system can have serious consequences in people's health because a poor sanitation environment is generated. Among the most common water diseases are dengue, cholera, and dysentery. But, in extreme cases, critical rates of malnutrition can occur like in Africa and Asia; where they have a rate of 23.8% and 46%, respectively [7]. Water pollution diseases are very common. In 2017, approximately 220 million people required treatment for schistosomiasis, a disease that originates from contaminated water. Another related disease is diarrhea where 842,000 people die each year, and which 43% are children under 5 years old and their death could be prevented considering their condition at risk. Japanese encephalitis, where 25% of clinical cases die, while 35% are left with permanent brain sequelae, and many others such as hepatitis A, schistosomiasis, and fluorosis, which are easily transmitted in an unsanitary environment [8].

Wastewater treatment plants management is an important problem. Not only for industries and municipal governments, but especially for environmental management and its impacts. If wastewater is managed improperly, then raw water supplies for transformation into drinking water will suffer. If wastewater is discharged without the necessary treatment, the environmental quality will be affected. To solve this, wastewater treatment focuses on reducing the amount of carbonaceous materials (organic; determined predominantly as biochemical oxygen demand) and, when sensitive waters are involved, nitrogen (N) and phosphorus (P) compounds, before from being discharged to the receiving systems [9]. The presence of these materials in high concentrations can have deleterious effects on the levels of dissolved oxygen (O_2) concentration, the trophic state and, ultimately, the well-being of the fauna and flora in the water.

There is a great disparity between developed and developing regions, as well as between rural and urban areas, especially in Latin America, South Asia and Oceania. In this zones, the values indicate that 7 out of 10 people who do not have access to basic sanitation, they live in rural areas [10]. Ecuador has indicated that 90% of the population has access to sanitary sewage systems in urban areas. But, Guayas province has a coverage of 61.7%, and the capital Guayaquil has coverage 73% of sanitary sewers. El Empalme is among the lowest in terms of sewerage coverage with a range of 10%–38% [11]. The parish of El Rosario has a excreta evacuation system which consists in putting domestic wastewater in a natural estuary that flows into the Daule River. The untreated discharge into the Daule River becomes a potential public health problem for the Guayas province, since this river network is a source of drinking water and irrigation for crops, which could cause gastrointestinal diseases [12]. One of the most common diseases in the study area is malnutrition, which occurs in most cases due to unsanitary conditions, encouraging the proliferation of different types of parasites. El Rosario has a chronic malnutrition rate of 43.8%, ranking among the highest percentages at the cantonal level and exceeding the global malnutrition rate of 16% [13], [14].

Regarding the techniques and methods described in the literature to address the issue of wastewater, the sewerage system includes a group of pipes added to typically reinforced concrete structures that help to correctly distribute the intervened flow. This system is strategically connected to collect and transport wastewater and/or rainwater, depending on its type and function [15]. Stabilization ponds are a simple method for treating wastewater, since it does not require sophisticated equipment, nor many resources for its construction, operation and maintenance. For the reasons stated, this type of depuration method is ideal to be implemented in small communities that do not count with many economic resources. In addition, stabilization ponds are very efficient in removing organic matter [16], which is a pollutant that characterizes domestic wastewater [17].

1.1 Objective

This document's objective is "to develop the design of the sewerage system and wastewater treatment system of the El Rosario parish, in such a way as to improve the quality of life of its inhabitants, and guarantee the water resource for human consumption, through the technical analysis of the study area and sustainability factors, mitigating the contamination of the parish and the Daule river". A simplified separative system is proposed as a sanitary sewerage and storm sewer system, added to a purification system that contains a grit tank and a set of stabilization ponds. This system has a bypass so that only the first rains of the winter season can enter the purification system, after this, the rainwater can be discharged directly to the Daule river.

1.2 General characteristics of the study area

The study area has a topography with elevations that vary from 25 to 75 masl, consequently it has micro-basins within its geographical limit that will allow the natural discharge of runoff. It is made up of 3 micro-basins that discharge to the Daule River at different points. Its current population was obtained by counting properties and statistical methods based on the last national census and on the average number of inhabitants per household in rural areas. Having a population for the year 2020 of 3,582 people.

The "El Rosario" parish of the El Empalme canton lacks a sewage and wastewater treatment system. The sanitary waste from each house is dumped into the natural stream that runs through the entire parish and finally flows into the Daule River. This action causes an unhealthy environment for the inhabitants of the parish, where the contamination of the estuary is added to the direct contamination of the river into which it flows. The river is a source of raw water to make the water of Greater Guayaquil drinkable (Guayaquil, Daule and Samborondón) affecting a total of more than 4,000,000 inhabitants.

2 METHODOLOGY

To develop the sewerage design applied to the parish head of El Rosario, a methodological sequence adapted to the case study was defined and applied. The steps followed were those indicated in Fig. 1.

In phase 1 the collection of relevant data such as: current population, information related to the provision of drinking water, topography, climate, and nearby micro-basins of the area is approached to obtain the design population and its flows. Since the study area does not currently record census data, the current population was determined by counting the properties and multiplying by a factor of 6, which is the average number of inhabitants per household in the area. With this information, we proceeded to design the sanitary sewage system for a period of 20 years, calculating the future population through arithmetic, geometric and exponential methods. Finally, for the preliminary information section, the hydrographic network of the area was determined, which allowed us to know the point of natural discharge of the waters and thus determine the drainage scheme of the storm sewer system.

In phase 2 the design of the sanitary sewer system is proposed. Specifically, the definition of the layout and design of the primary, secondary and tertiary routes for the discharge of

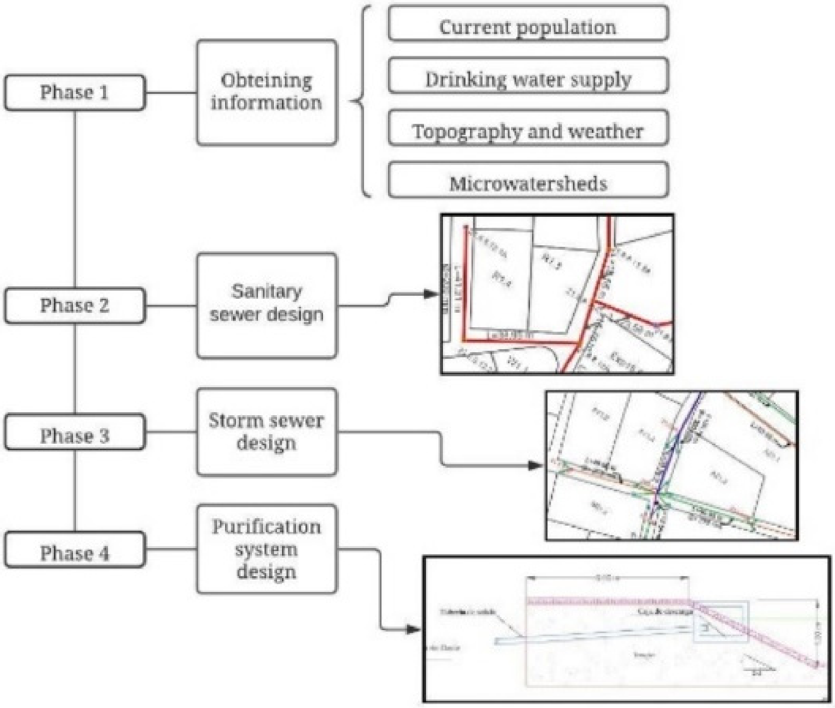

Figure 1: Methodological scheme.

domestic water. The first step was to trace the route of the collectors so that they follow the natural shape of the terrain and avoid the implementation of pumping stations. In this step, revision wells were located at each change of direction and at a maximum separation of 100 m. Then, the contributing and expansion areas were distributed for the different revision wells and the tributary and accumulated areas were calculated. Next, the domestic, institutional, infiltration flows with a factor of 0.15 l/s/ha and illegal water with a factor of 0.2 l/s/ha were calculated. The supply of drinking water taken was 100 l/hab per day, and a return coefficient of 0.8 was used for its transformation into wastewater. From the flow rates obtained, the slopes and diameters were established in accordance with the commercial diameters available in the country. Errors were corrected by means of hydraulic relations and the parameters were verified to check if the slopes, diameters, speeds, and tractive force, within the pipes, are adequate to allow the rapid evacuation of the sewage, without producing sedimentation. or gas production, and preventing erosion by high speeds within the pipes. As a check, you have to ensure:

1. $T > 0.12$ (guarantee traction)
2. $V_{min} \geq 0.45$ m/s (guarantee self-cleaning)
3. $V_{máx} \leq 4.5$ m/s (avoid erosion)

If these parameters are not fulfilled, changes in diameters or slopes must be done.
Finally, the start and end terrain, crown, water line, and invert elevations were calculated for each section. These were sketched for a better on-site view and to verify its functionality (see Figs 2 and 3).

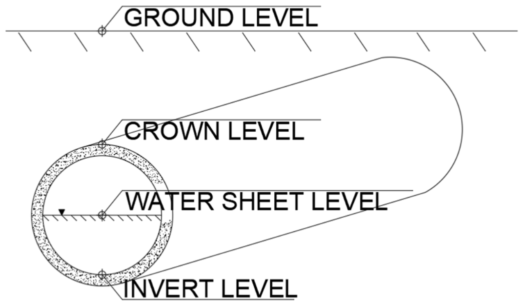

Figure 2: Location of the different dimensions in the collector cross section.

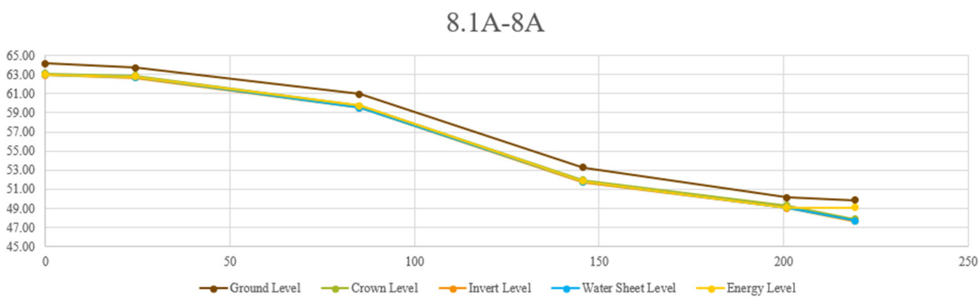

Figure 3: Diagram of dimensions in section 8.1A-8A.

3 RESULTS

The results for sanitary sewer, storm sewer and treatment plant are shown in Tables 1–4.

4 ANALYSIS OF RESULTS

The population estimate is as expected for these rural communities. The water supply is a bit high, taking into consideration that for rural areas it is usually between 50–60 L/person per day, this could be explained by the tropical climate or by losses in the drinking water pipelines.

Table 1: Data results about population, topography and drinking water supply.

Population	
Current (2020)	Future (2040)
3,582 hab	4,846 hab
Topography	
Min.	Max.
15 msal	75 msal
Drinking water supply	
100 L/hab/day	

Table 2: Data results from sanitary and storm sewerage systems.

Sanitary sewerage system		
Length	19.20	km
Diameter	200–250	mm
Slope	0.005–0.4	m/m
Storm sewerage system		
Length	6.80	km
Diameter	250–700	mm
Slope	0.005–0.4	m/m

Table 3: Screen and grit results.

Screen		
Dimensions	30×15	mm
Grit		
Volume	1.8	m^3

Table 4: Ponds for clean water results.

Facultative ponds		
Quantity	4	u
Width	47	m
Length	90	m
Deep	1.5	m
Retention (dry season)	11	days
Retention (wet season)	8	days
Removal (dry season)	79.52	%
Removal (wet season)	73.85	%
Incoming flow	2,280.96	m^3/day
Maturation ponds		
Quantity	2	u
Width	71	m
Length	140	m
Deep	1.3	m
Retention (dry season)	12	days
Retention (wet season)	9	days
Removal (dry season)	90.50	%
Removal (wet season)	86.32	%
Incoming flow	1,569.51	m^3/day

The acquired topography is quite consistent with the evident unevenness in the parish. The micro-basins found agree with the natural exhaust route of the estuary that crosses the parish.

The sanitary sewer system has pipe dimensions and slopes that follow the provisions of the CPE INEN 5 PART 9-1 standard, guaranteeing that there will be no sedimentation or

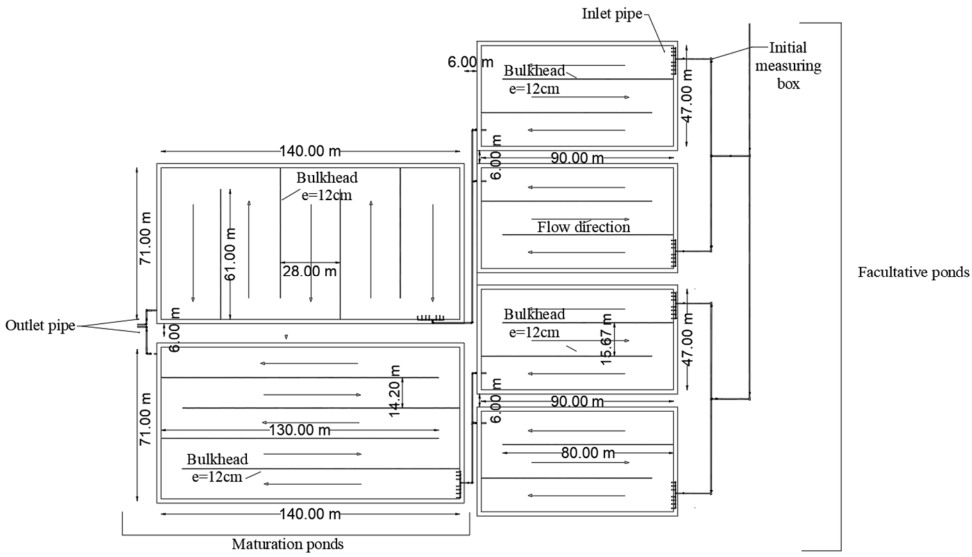

Figure 4: Diagram of depuration ponds.

erosion within the collectors. On the other hand, the storm sewer was drawn only in the paved areas in order to avoid obstructions by mud, stones and sticks; for them it has a shorter total length.

Because the location of the treatment plant is at a higher elevation, due to the lack of space in the initial site, it has been decided to implement a pumping station that works from two centrifugal pumps of 20 HP. The treatment plant will comprise sieves 30 mm × 15 mm, for removing solid particles larger these openings in the area.

When calculating the volume of the facultative lagoons, it was obteined a retention time of 11 days in dry weather and 8 days in rainy season was obtained. This implies that the design process is correct with the values recommended by Crites and Tchobanoglous [18], which stands out a range between 7.5 and 22.5 days.

The configuration of the lagoon system depends on the designer's criteria, but is based on economic and biological aspects of the place of implantation, as well as the facilities for operation and maintenance (OPEX). Taking this consideration, the system will consist of two design lines. Additionally, the lagoon system is considered the most efficient solution in rural areas where low-skilled labor is required for OPEX and where the cost of land is not significant.

For the 2-line design system, the configuration of each line comprises: two facultative ponds in parallel connected to a maturation pond in series. This completes the retention times for each one and removes the amount of pollutants acceptable for discharge, of 100 mgO_2/L for BOD5 and 1,000 MPN/100ml for coliforms, in accordance with local regulations. However, in this case, they went further, the removal of fecal coliforms and BOD5 at the end of the process indicate an efficiency of 91%. It was obtained a final concentration of BOD5 of 17.11 mgO_2/L in dry weather, and an efficiency of 86% in the rainy season, with a final BOD5 concentration of 24.62 mg/L, which allows the reuse of the waters in possible initiatives for resource recovery.

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5 CONCLUSIONS AND RECOMMENDATIONS

From the information obtained in phase 1, it was possible to carry out a sewer network design where the topography helped it to work under gravity in its task of collecting and transporting household waste, however, because the treatment plant It is in an area located above the flood level, a pumping point made up of two 20 HP centrifugal pumps was required.

Diameters were calculated in such a way that the most economical is obtained so that the sewer design is efficient with respect to the common problems that occur in pipes, such as sedimentation or erosion. Thus, system failures or collapses are avoided, and maintenance concurrency is reduced. This design phase contemplates an approximate cost of USD 624,836.60.

For the design of the rainwater network, a design that requires the least possible budget and maintenance expenses was defined, giving an estimate of USD 559,776.65. In the same way as the sanitary sewer network, economic diameters were chosen for the pipes. It was also verified that the speeds do not allow sedimentation and the self-cleaning of the network is guaranteed.

A stabilization pond system was selected as a purification system because this type of system is ideal for a developing rural population. Furthermore, this water purification proposal presents low maintenance and operation costs. This lagoon system has an estimated referential budget of USD 393,954.77.

To improve management of the construction process of the sewerage network, it is essential to carry out a study of the location of existing drinking water supply pipes. Thus complying with standards of distance between sanitary and drinking water pipes. In this way, a design that does not interfere with the existing supply network can be made.

When designing lagoons for a rural area it is important to take into account the availability of a large area for the location of the lagoons. It is recommended, not only that the area is large, but that it is located at a prudent distance from the residential area to avoid the transport of bad odors to inhabited areas. Also consider aspects of the climatic conditions of the site, observe which is the predominant orientation of the wind and arrange the lagoons in that sense.

The design of the sewerage and wastewater treatment system of the El Rosario parish allows the GAD to have an estimate of the cost of the system, to foresee its financing and construction. The projected budget for this project is USD 2,157,100.35, broken down as follows: USD 624,836.60 corresponds to the sanitary sewer, USD 559,776.65 the storm sewer, USD 966,990.66 the purification system and USD 5,496.43 due to the expenses generated by environmental impact. The total work will have an estimated duration for construction of 9.5 months.

Due to the mobilization restrictions because of COVID, the topography data could not be verified, therefore, as a recommendation, it is indicated to adjust these values and the corresponding trace, when the COVID-19 pandemic ends. Try to carry out corresponding sampling at the outlet of the household guides to characterize the domestic discharge and correct the pollutant load with which it reaches the purification system, however, it is considered that the value of 180 mgO_2/L for the BDO5 is correct, depending on of the results found in other nearby sites.

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