water

MDPI

Article

Zootechnical Farm Wastewaters in Ecuador: A Treatment Proposal and Cost-benefit Analysis

Paola Verlicchi [1,2,*], Estefania C. Avilés Sacoto [1,3] and Giacomo Zanni [1]

1 Department of Engineering, University of Ferrara, Via Saragat 1, 44122 Ferrara, Italy; estefania_a_s@hotmail.com (E.C.A.S.); giacomo.zanni@unife.it (G.Z.)
2 Terra & Acqua Tech Tecnopolo Ferrara, University of Ferrara, Via Borsari 46, 44121 Ferrara, Italy
3 Department of Environmental Engineering, Universidad Politécnica Salesiana, Calle Vieja 12-30 y Elia Liut, 010105 Cuenca, Ecuador
* Correspondence: paola.verlicchi@unife.it; Tel.: +39-0532-974938

Received: 19 March 2019; Accepted: 12 April 2019; Published: 15 April 2019

check for updates

Abstract: This paper presents and discusses the results of a study carried out in Ecuador, where the zootechnical sector represents one of the country's most important economic activities. It is, however, the source of many environmental problems, including the release of untreated liquid effluents and odorous emissions, and the production and disposal of solid wastes. The main aim of this study was to propose a treatment train for the zootechnical farm wastewater, combining natural systems (i.e., lagoons and subsurface flow beds) with conventional technologies and a cost-benefit analysis. With reference to a specific case study, the different steps of the treatment train were designed and the corresponding construction, operational and maintenance costs evaluated. To better assess the technical and economic feasibility of such a proposal, a cost-benefit analysis was carried out. The social benefit was evaluated by means of the contingent valuation method and a focus on the methodology and collected results was reported. The main findings discussed, in terms of selected treatments, their costs, and the financial and economic analysis of the project, could be useful for administrators, decision-makers and all technicians involved in planning and management of zootechnical farm wastewaters in developing countries, in particular in Latin America.

Keywords: constructed wetlands; cost-benefit analysis; economic analysis; financial analysis; wastewater treatment plant; willingness to pay; zootechnical farm wastewater

1. Introduction

Concern regarding (fresh) water is increasing worldwide–in many countries attention is increasingly being paid to its availability–which is reducing–and to its quality–which is worsening. In areas in some developing countries there is no access to drinking water; in most of them domestic, as well as industrial and zootechnical farm wastewaters may be directly released into water bodies without any kind of treatment [1]. As a consequence, the quality of both the receiving water and the surrounding environment is getting worse, and the risks for human health are increasing. Recently, the Water Bank Group reported that 24% of the rural population in Ecuador drinks contaminated water, only 7% of the population in Haiti has access to good quality water and only 5% of the urban wastewater is treated in Indonesia [1]. Inappropriate or incomplete (urban, industrial and zootechnical farm) wastewater treatments are one of the main causes of the progressive deterioration of the quality of the receiving surface waters. This fact may compromise the final use of such water, be it for drinking, irrigation, bathing or other recreational activities.

In managing and treating wastewater, different treatment levels can be pursued (by adopting primary, secondary and polishing steps) and different approaches followed (by adopting conventional, natural treatments or a combination of both) [2]. Limiting the attention to the latter point, it is important to remark that in developing countries, natural systems such as lagoons and subsurface flow constructed wetlands are quite attractive as they are based on simple technologies that do not require qualified personnel for the operational and maintenance phases and are characterized by relatively low running costs [3]. Their main weakness is related to the large area required to guarantee the desired removal of the different pollutants when compared to compact technologies, such as trickling filters, conventional activated sludge systems or membrane bioreactors [4]. According to [5], natural treatments require surfaces 20–30 times wider than the cited compact systems. In developing countries, wide areas are often available for the construction of a treatment train including such extensive systems.

This study refers to a project carried out in a region of Ecuador related to the treatment of zootechnical farm wastewaters which are usually released into receiving water bodies without any kind of treatment. The zootechnical sector is one of the most important activities in this country and the main issue related to the current practice of management and treatment of the produced effluents is waste generation (manure and liquid effluents). The study refers to a specific farm area in Ecuador characterized by the presence of 100 cows, making it a typical medium-sized farm in the country. A treatment train based on conventional pretreatments and extensive natural treatments (constructed wetlands) was proposed and a cost-benefit analysis carried out by following the financial and economic approaches. The main features of the treatment plant and its technical and economic feasibility are presented and discussed in this paper, with a focus on the contingent valuation method adopted for the evaluation of the social benefit of the treatment plant and an analysis of the results collected due to its application.

2. Materials and Methods

2.1. The Area under Study

This study was conducted in the canton of Paute (2°16′44.4″ S; 78°45′39.6″ W), located in the Azuay province approximately 42 km west of Cuenca city. It has an area of 271 km^2, a population of 25,494 inhabitants and is divided into eight zones, with the resident population reported in Figure 1. According to [6], a typical family includes four members; thus, the total number of families resident in the area under study is 6374, and their distribution among the different regions is shown in Figure 1. The weather is warm throughout the year and temperatures vary within the range of 15–27 °C in any month.

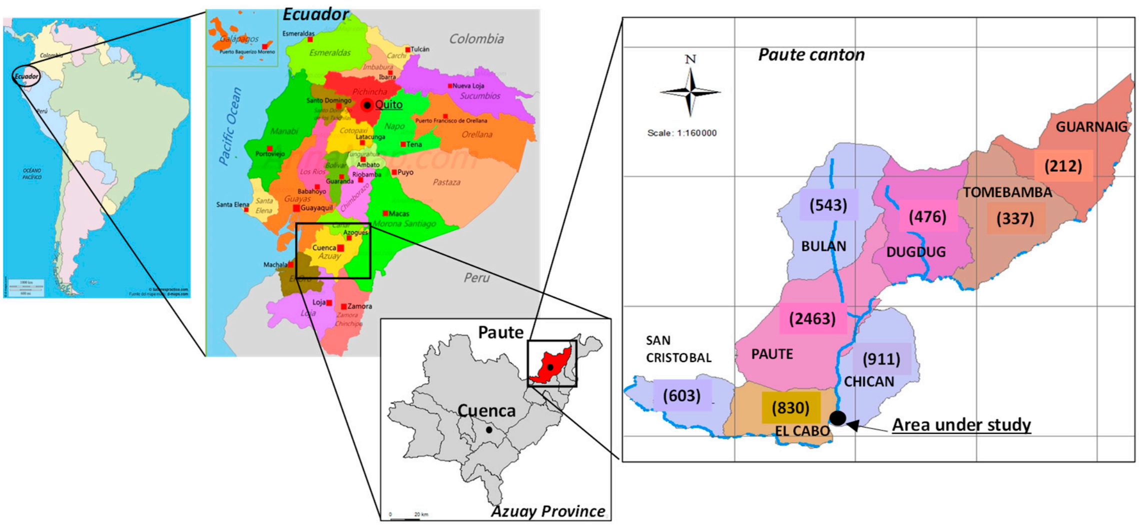

Figure 1. The study area in the Paute canton and the corresponding resident families (in brackets) for the eight different zones.

This is mainly an agro-livestock area–the land use map of Paute shows that 70% of the surface of the territory has agro-livestock uses, 26% of its surface is occupied only by pastures for feeding livestock [7] and 42% of the economically active population works in this production sector [6]. In this town there are 4003 production areas and 19,327 heads of bovine cattle [8].

The typical production areas are small and medium sized and are still equipped with poor technology in the milk production area. This scarcity or absence of technology affects the management and treatment of waste produced daily and is the cause of several environmental problems.

According to the Development and Land Management Plan of Paute [9], it has been established that the main cause of pollution of the water sources in this area is due to the presence of livestock production areas whose waste (i.e., wastewaters and manure) is directly released into the rivers or spread on the soil without any kind of treatment.

2.2. Zootechnical Farm Wastewater

The present study refers to a typical medium-size production area, this being the most common farm size in Ecuador, which covers 90.7% of the total national production areas [8].

The study area is located in the south part of the Chicán area near the El Cabo zone (Figure 1) and has, on average, 100 heads of bovine cattle. It consists of a stall and an adjacent milking area (Figure 2A), facilities for workers (toilets and changing rooms), there is continuous access to water and occasionally to electricity for the stall area and the milking area is equipped with machines for electrical milking. Poor cleaning and washing systems are present in the two areas and no treatment is provided for the generated wastes (manure and wastewaters). The zootechnical area is characterized by a production of 5 kg/(cow day) of manure (resulting in a total amount of 500 kg/day), which is removed from the stall and the milking areas, accumulated in an open space close to the stall and the agricultural crops, where it is regularly disposed of. Wastewaters derive from the cleaning operations in the stall as well as from the milking area (Figure 2B). Both places are washed twice a day, resulting in a discontinuous production of wastewater flow rates over the day: at midday and early in the afternoon from the stall, and around 9 am and soon after milking operations are completed and all the machines need to be washed and cleaned (at around 5 pm). It was found that wastewater from the stall may vary between 4 and 9 m^3/day, on average 6 m^3/day, and from the milking area between 5 and 7.5 m^3/day, on average 6.2 m^3/day. Stall wastewater is currently directly released into the Paute River; milking wastewater is conveyed into the sewage system and released into the same water body a few meters further on. This practice would be abandoned in the case of the construction of a wastewater treatment plant (WWTP) as all the production areas would convey their effluent directly to it. In order to ascertain the qualitative and quantitative characteristics of the produced wastewater, an experimental campaign was carried out in January-June 2017 on 40 water grab samples taken from the two areas (milking and stall). Water samples were taken once a week, during the two wastewater generation periods described above (in the milking area from 9 to 10 am and from 5 to 6 pm and in the stall from 12 pm to 1 pm and from 1 to 2 pm) in both production areas. For each sampling day i, the flow rate Q (m^3/day) and the concentration c (g/L) of each monitored pollutant j were evaluated by a mass balance according to Equations (1) and (2):

$$Q_i = Q_1 + Q_2 \tag{1}$$

$$c_{j,i} = \frac{c_{j,1}\ x\ Q_{j,1} + c_{j,2}\ x\ Q_{j,2}}{Q_1 + Q_2} \tag{2}$$

The monitored pollutants are listed in Table 1 and refer to the main parameters included in the local regulation called TULSMA [10]: biological oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), total nitrogen (TN) and total phosphorus (TP). They were measured according to APHA standards Standard Methods for the Examination of Water and Wastewater [11]. Flow rate measurements were carried out with the volumetric method described in [12].

Figure 2. The study area: (**A**) production area; (**B**) zootechnical wastewater generation and conveying.

Table 1. Zootechnical wastewater characteristics in terms of flow rate and main chemical parameters (biological oxygen demand (BOD5), chemical oxygen demand (COD), total suspended solids (TSS), total nitrogen (TN) and total phosphorus (TP).

Parameter	Mean ± SD	Minimum	Maximum	Legal limits [10]
Flow rate, m^3/d	12 ± 1.4	9.2	14.5	
COD, mg/L	3495 ± 1204	1513	5700	250
BOD_5, mg/L	1613 ± 679	679	2803	100
TSS, mg/L	1133 ± 402	522	2203	100
TN, mg/L	140 ± 56	70	252	15
TP, mg/L	43 ± 10	28	62	10

2.3. The Proposed Treatment Train

The aim in developing a proposal for the treatment of this kind of wastewater was to provide a treatment train which was simple and easy to construct and manage, characterized by low investments and running costs. A treatment train based on a combination of conventional and natural treatment technologies is desirable.

2.4. Cost-Benefit Analysis

Cost–benefit analysis (CBA) is one technique used for analyzing projects to determine whether or not they are in the public interest. CBA assigns a monetary value to each input and output resulting from the project, and values are then compared. In general, if the value of the incremental benefits is greater than the value of the incremental costs, the project is deemed worthwhile and can be implemented. It may refer to a single project in order to evaluate if it has to be accepted or refused. Alternatively, it may be applied to different projects with the aim to create a ranking among them. In this study, we followed the first approach. It is important to observe that also in this case there is an implicit comparison between two alternatives: the scenario "with the project" and the scenario "without the project" (the so-called counterfactual). Costs and benefits have to be intended as incremental costs and incremental benefits with regard to the counterfactual.

The current study was carried out by developing a financial analysis and an economic analysis. Financial analysis assesses project profitability from an entrepreneurial point of view. Economic analysis is carried out to appraise the project's contribution to welfare. The methodology used is the Discounted Cash Flow method. Project cash flows cover a time horizon of 20 years, considered appropriate to the project's economically useful life and its likely long-term impacts.

In the financial analysis, the assessed costs were: (i) initial investment, associated with the construction of the treatment train (assuming the plant is completed in one year) and (ii) the incremental operating and maintenance costs, occurring every year of the time horizon (lifespan).

With regard to the expected financial benefits, it was assumed that, due to the adoption of an adequate treatment train, the plant would avoid the risk of fines and pecuniary sanctions, due to the release of polluted and untreated effluents, according to local law. The expected frequency of checks by the administrative and control bodies was estimated to be every five years.

The economic analysis began by the examining the financial analysis data, in accordance with international practice [13]. On this basis, some adjustments were made, transforming the market prices into shadow prices and cutting taxes, subsidies, fines and all other forms of government intervention. The socio-economic benefit is connected to the improvement of the level of welfare of the population, as a result of the treatment train's activity. It was estimated by means of the willingness to pay (WTP) of the resident population, as a contribution to the construction of the proposed treatment train. This benefit was evaluated by means of the approach presented in [4,14] for the evaluation of the social benefit of reclaimed wastewater for reuse in Italy.

The analysis is carried out at constant (real) prices, fixed in 2018. Consequently, the discount rate, reflecting the opportunity cost of capital in financial analysis and the social discount rate in economic analysis, is expressed in real terms. In both analyses, the adopted rate is 8%.

2.4.1. Willingness to Pay (WTP) Evaluation–The Questionnaire

This study evaluated public acceptance of the project by means of the Contingent Valuation Method (CVM). This attempts to determine the market price of non-market goods and services, and is the most widely-used method in evaluating environmental assets [15] by surveying peoples' willingness to pay (WTP) for such an asset and/or what they would be willing to receive by way of compensation in order to tolerate such a cost, i.e., preservation of a natural park, the upgrading of a wastewater treatment plant or the restoration of a damaged area via infrastructure development [16–20]. An example of CVM applied to evaluate the non-market value of reclaimed wastewater for reuse in agriculture is provided by [21] in a Spanish study. In order to apply CVM, it is necessary to interview subjects or provide them with questionnaires to elicit their WTP for a benefit via one or several payment mechanisms.

A questionnaire leading to the evaluation of the willingness to pay of the resident population was prepared and adapted from the one used by [14] in their study. The questionnaire consisted of 21 questions divided into three parts. All questions were multiple-choice. Respondents had to be resident in the study area and report the opinion of their family.

The first part of the interview evaluated how much the population is involved with environmental issues. It had to assess how much importance should be given to environmental protection, how good the quality of the environment in the study zone should be and it also analyzed respondents' level of knowledge regarding wastewater treatment systems and those proposed in this case study for the zootechnical farm wastewaters (in particular lagoons and subsurface flow beds).

The proposed treatment system was described to the interviewees with a brief presentation of the adopted treatment steps, the pollutants to be removed, and its construction and operational and maintenance costs. Finally, a brief presentation of the socio-environmental benefits of the construction of the treatment train completed this first part.

The second part focused on the respondent's opinion regarding the project.

This part consisted of an evaluation of the amount of money that they would give for the construction of the proposed treatment system which would improve the quality of the receiving water body as well as of the surrounding environment (absence of bad odors). It was immediately stated that there would be just one single sum (*una tantum*) to support the construction of the system to treat zootechnical farm wastewaters. Some monetary amounts were established; however, in order to reduce bias, an option that allowed them to propose a different amount was also presented. The proposed card with the different options is reported in Table 2.

In order to obtain a representative sample, all respondents included were residents in the different zones of the studied area (Paute), and their opinions were taken to reflect those of their family.

Finally, the third part of the questionnaire consisted of the collection of general information regarding age, education level, job title and annual income in order to relate the WTP with demographic and socioeconomic variables.

The survey was carried out through face-to-face interviews by personnel specially trained in this type of methodology.

Table 2. Card proposed to each respondent for the selection of his/her willingness to pay (USD).

1	15	35	60	100	300
2	20	40	70	150	500
5	25	45	80	200	700
10	30	50	90	250	1000
Other (specify)					

2.4.2. WTP Survey

The number m of respondents was defined on the basis of Slovin's formula $m = N/(1 + N e^2)$ where m is the sample size, N is the universe of interest (that is, all the potential respondents in the area of study) and e is the desired (acceptable) margin of error, adopted in many other studies [4,22]. With a resident population in this area of 25,494 inhabitants, and assuming four members in each family [23], N = 6374 families; assuming e = 0.05, for the specific investigation, it was found that the number of respondents across Paute m was 376.

The survey campaign took place during the period between May and August 2018 and the real number of respondents was 510 (a higher number than the minimum representative threshold of 376). These respondents were randomly selected from the eight different zones of Paute and represent 8% of the resident families in each zone (see Figure 1).

2.4.3. Economic Indicators Used in CBA

The project economic feasibility is evaluated on the basis of common economic indicators. The most used is the Net Present Value (NPV), defined by Equation (3):

$$NPV = \sum_{k=0}^{n} \frac{-C_k + B_k}{(1 + r)^k} \tag{3}$$

where C_k and B_k are, respectively, the costs and the benefits in the year k, r is the discount rate and n is the expected plant lifespan.

If NPV ≥ 0, the implementation of the project is acceptable from an economic point of view; if NPV < 0, the investment should be rejected, as the costs outweigh the benefits.

Other indicators evaluated were:

- The Benefit-Cost Ratio (BCR) defined as the present value of benefits divided by the present value of costs Equation (4):

$$BCR = \frac{\sum_{k=0}^{n} \frac{B_k}{(1+r)^k}}{\sum_{k=0}^{n} \frac{C_k}{(1+r)^k}} \tag{4}$$

- The Pay-Back Period (PBP) is defined as the first year in which the benefit covers the accrued cost, which is the first year in which the cumulative NPV is > 0.
- The Internal Rate of Return (IRR) is defined as the discount rate that equates the present value of the overall benefit and the present value of the overall cost Equation (5):

$$\sum_{k=0}^{n} \frac{B_k}{(1+IRR)^k} = \sum_{k=0}^{n} \frac{BC_k}{(1+IRR)^k} \tag{5}$$

The implementation of the project is acceptable if BCR ≥ 0, PBP ≤ *n* and IRR ≥ *r*.

3. Results and Discussion

3.1. The Proposed Wastewater Treatment Train

The wastewater treatment train aims to respect the local legal requirements (reported in Table 1) for the release of the final effluent into the surface water body and consists of the sequence reported in Figure 3. The sizing of each step is briefly described in the following and the principal design parameters are reported in Table 3. Most of the treatments are based on biological processes, which are strictly related to environment conditions, namely ambient temperature. In this context, the assumed value of temperature in sizing horizontal subsurface flow (HSSF) and vertical subsurface flow (VSSF) beds was equal to 15 °C, corresponding to the lowest limit in the observed temperature interval in this area. Horizontal and vertical subsurface flow beds were designed following the well-known methods reported in [3] and the empirical criteria reported in [5] referring to the maximum suggested organic load fed to the beds in order to guarantee a desired removal and to avoid clogging. An in-depth description of the sizing of the different steps is reported in [24].

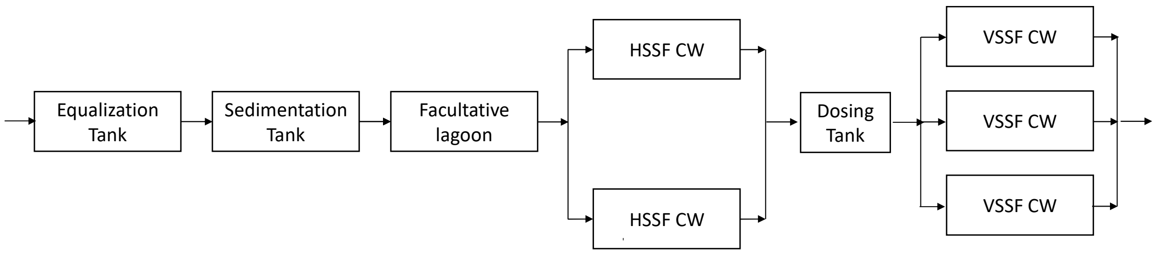

Figure 3. Diagram of the treatment train proposed for the zootechnical farm wastewater.

Table 3. The main design parameters of the different treatment steps.

Step	Length (m)	Width (m)	Height (m)	HRT	Medium	Vegetation
Equalization tank	4.75	2	1	-	-	-
Sedimentation tank	1.28	0.32	3	2.42 h	-	-
Facultative lagoon	20	5	1.8	15 day	-	-
HSSF CW* (2 beds) For each bed	26.5	20	0.6	18 day	Fine gravel 16 mm Porosity ε = 0.35 Hydraulic conductivity 10^4 m/day	*Ph. australis*
Dosing tank	2	1.5	1	-	-	-
VSSF CW* (3 beds) For each bed	14	10	0.6	8 day	Fine gravel 16 mm Porosity ε = 0.35 Hydraulic conductivity 10^4 m/day	*Ph. australis*

* HSSF-CW = Horizontal Subsurface Flow Constructed Wetland; VSSF CW = Vertical Subsurface Flow Constructed wetland.

Equalization–This step sees collection of the intermittent flow during the washing and cleaning of the two areas and of the machineries (only twice a day) and guarantees a constant hourly feeding to the following step. An average daily flow rate of 12.2 m^3/day was assumed, corresponding to a constant hourly outflow of 0.51 m^3/h. Based on the collected data regarding the influent flow rate during the experimental campaign, and by assuming a safety factor of 1.2 for the design of the equalization tank, the volume of the equalization tank resulted equal to 9.5 m^3. This volume is able to guarantee a modest equalization of the load for all the analyzed pollutants [24].

Sedimentation–This step completes the sedimentation of the high quantity of suspended solids conveyed to the treatment system. This tank was designed according to [2]: an average hydraulic loading rate of 1.25 m/h was assumed and a tank depth of 3 m. The expected removal efficiencies are 30% for BOD_5 and COD, 60% for suspended solids, and 10% for TN and TP.

Facultative Lagooning–This step promotes the biodegradation of the organic content and protects the two following subsurface flow beds from clogging. The basin was designed on the basis of the hydraulic retention time assumed equal to 15 days. Based on literature results, removal efficiencies of 40% for BOD_5 and COD and 50% for suspended solids, TN and TP were assumed.

Horizontal Subsurface Flow Constructed Wetlands (HSSF CW)–These two beds operate in parallel in order to guarantee continuity in case one should be undergoing maintenance. Each bed was sized on the basis of the following parameters: height equal to 0.6 m, slope 1%, biodegradation constant rate at 15 °C equal to 0.12 m/day, filling medium porosity equal to 35% and hydraulic conductivity 10^4 m/day. It was then verified that in each bed the maximum applied organic load did not exceed 10 g/(m^2 day) to avoid clogging phenomena and promote the biodegradation or organic compounds. The expected removal efficiencies were 75% for BOD_5 and COD, 60% for suspended solids and 30% for total nitrogen and total phosphorus.

Storage–This tank (often called dosing tank) allows the effluent to be collected from the horizontal subsurface flow beds running in continuous mode, and guarantees intermittent feeding to the following vertical flow beds. The dosing tank was designed assuming its volume equal to 20% of the daily volume of wastewater to be treated.

Vertical Subsurface Flow Constructed Wetlands (VSSF CW) working in parallel, in order to guarantee system operation in case one or two beds should require an unexpected or prolonged period of maintenance. They were designed on the basis of an organic load equal to 5 g BOD_5/(m^2 day), 24 feeding doses, a filling medium height equal to 0.6 m. The expected removal efficiencies were 70% for COD and BOD_5, 60% for suspended solids, 70% for total nitrogen and 30% for total phosphorus.

Assuming these design parameters, it is expected that all the legal limits reported in Table 1 are fulfilled. In this study we did not analyze the efficiency of the treatment plant in removing microorganisms, in particular *E. coli*. According to the available literature [4,5], the removal efficiencies of *E. coli* in the different proposed steps can be assumed of 50% in the settling tank, 99.99% in the lagoon and 99% in HSSF and VSSF beds. Assuming an occurrence of *E. coli* in the raw wastewater equal to 10^9 MPN/100 mL [3], on the basis of the reported removal efficiencies, the treated effluent will have a concentration of 1250 MPN/100 mL.

The footprint of the complete treatment train corresponds to 1676 m^2. With regard to the average daily flow rate of 12.2 m^3/day, assuming a specific water consumption of 150 L/inhabitant day, the population equivalent (PE) served by the treatment plant will result of corresponds to 81 PE and the specific land requirement of 21 m^2/PE. Assuming a specific daily BOD_5 production of 60 g/(PE day), the equivalent population served by the treatment plant corresponds to 398 PE and the specific land requirement of 5 m^2/PE will be met. The different values for the specific land requirements evaluated on the basis of the specific flow rate and the specific organic load are clearly due to the type of wastewater fed to the treatment plant, which is more concentrated than typical domestic wastewater (see, for instance, [4]).

Other treatment trains could be suggested and developed for this kind of wastewater, including conventional treatment plants requiring small footprint but characterized by higher investment costs as well as higher operational and maintenance costs [25]. In addition, they should require qualified personnel for the running and ordinary and extraordinary maintenance. For these reasons the treatment train developed in this study was devoted to natural-based solutions.

3.2. Financial Analysis

The evaluation of the construction costs for the different steps, and of the operational and maintenance (O&M) costs (plantation and cutting of vegetation, cleaning, maintenance of civil infrastructures, wastewater analysis and administration costs), are reported in Table 4, expressed in USD.

Table 4. Cost estimation (market prices).

Cost Type	Amount
Construction (USD)	66,658
Operation and maintenance (USD/year)	3600

If costs are related to the treatment plant size, expressed in terms of population equivalent (398 PE with regard to the pollutant load), it was found that specific investment costs amount to 167 USD/PE and O&M costs amount to 0.90 USD/(PE year). The first is similar to those found in [4], whereas O&M specific costs are lower than those found in the cited study. The differences are due to the different unitary costs of materials and maintenance in the country under study.

If, as shown in Table 4, construction of the treatment plant is expected to increase operating costs, positive impacts on revenues are not expected. The only positive effect, from the point of view of financial benefits, is related to the fact that the local regulations impose severe fines on activities which contribute to the deterioration and pollution of water bodies. A specific treatment plant in operation will avoid the risk of fines. In particular, the Ecuadorian law "Ley Orgánica de Recursos Hídricos, Usos y Aprovechamientos del Agua" [26] considers the release of polluted waters into the aquatic environment a very serious infringement and the corresponding fines are between 51 and 150 basic salaries (each corresponding to 386 USD). For prudential reasons (since these are benefits), the lowest value (51) was assumed, leading to a fine of 19,686 USD (= 386 × 51).

Based on information obtained from local institutions, it has been assumed that the expected frequency of technical checks on a farm, regarding compliance with pollutant emission regulations, is approximately every five years. Therefore, the five-year value is transformed into an annual value (USD 3937), by dividing by 5. Table 5 shows the outflows (costs) and inflows (benefits) related to the financial analysis, as well as the results of the evaluation of the selected indicators.

Table 5. Financial Analysis applied to the case study: flows and results (economic indicators: Net Present Value NPV; Benefit Cost ratio BCR; Internal Rate of Return IRR; Pay Back period, PBP).

Year	Costs C_k (USD)	Benefits B_k (USD)	B_k-C_k (USD)
0	66,658		−66,658
1	3600	3937	337
2	3600	3937	337
3	3600	3937	337
4	3600	3937	337
5	3600	3937	337
6	3600	3937	337
7	3600	3937	337
8	3600	3937	337
9	3600	3937	337
10	3600	3937	337
11	3600	3937	337
12	3600	3937	337
13	3600	3937	337
14	3600	3937	337
15	3600	3937	337
16	3600	3937	337
17	3600	3937	337
18	3600	3937	337
19	3600	3937	337
20	3600	3937	337
NPV (USD)		−63,349	
BCR		0.49	
IRR (%)		−16%	
PBP (year)		Never	

Given the hypotheses, the project is not profitable from a private point of view: NPV amounts to −63,349 USD and IRR is also negative (−16%). This result is consistent with the empirical evidence, showing that this type of investment is rarely planned and adopted in the area under study. A sensitivity analysis, carried out by progressively increasing the frequency of expected compliance checks (and also of fines and benefits) shows that the project would become profitable if it was assumed that the fine would be given no more than every 2.5 years, as reported in Figure 4.

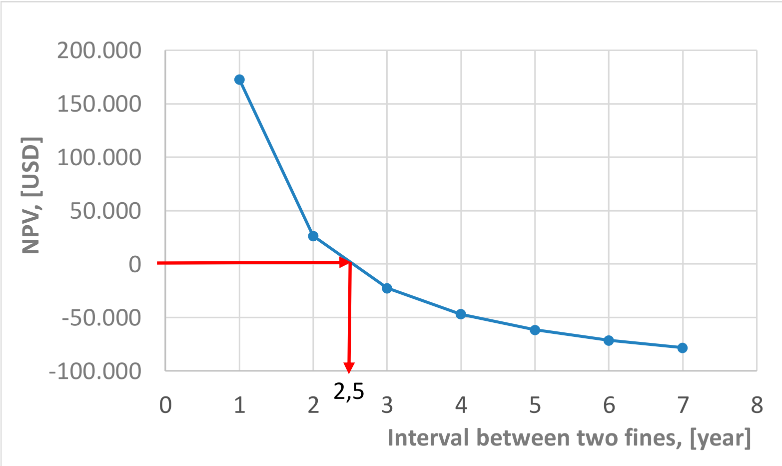

Figure 4. Sensitivity analysis referring to the parameter Interval between two fines.

3.3. Economic Analysis

In the economic analysis, benefits and costs were calculated on the basis of the estimates made in the financial analysis (Table 4), after adjusting the market prices to shadow prices, in order to take externalities into account, as well as to eliminate tax effects, government interventions and other market distortions.

The social-environmental benefit was evaluated by means of the willingness to pay (WTP) method following the approach discussed in detail in [4,14] regarding the evaluation of the social benefit in a reclaimed water reuse project in Italy.

Figure 5 reports the distribution of the WTP among the 510 respondents collected in the current study in terms of WTP level versus respondents.

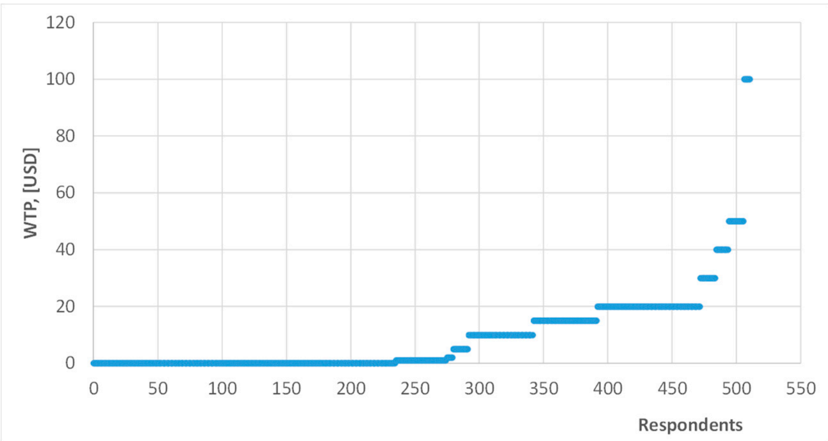

Figure 5. Distribution of the willingness to pay (WTP) in the present study.

The number of respondents decreases as the WTP rises. Of the 510 respondents, 235 (corresponding to 45%) are not willing to contribute to this project (WTP = 0 USD). For prudential reasons, the interviewees who refused to respond (the so-called protests) are considered in the same way as those who declared a WTP equal to zero. For 236 respondents 0 < WTP ≤ 20 USD; for 22 respondents it was 20 < WTP≤ 40 USD, for 12 interviewed it was between 40 and 60 USD. Only five respondents were willing to offer over 60 USD. The maximum value of WTP in this survey is 100 USD. The average WTP of the sample is 9.45 USD. Since each respondent represents his/her family, this value was multiplied by the number of resident households in this area (equal to 6374). The una tantum global WTP P_0, referring to all resident households is 60,234 USD.

This *una tantum* value corresponds to a series of 20 constant annual payments p (expressed in USD, calculated with a discount rate r of 8%). The annual amount p is calculated on the basis of the well-known Equation (5):

$$p = P_0 \frac{r\,x\,(1+r)^n}{(1+r)^t - 1} \quad (6)$$

where n is the expected treatment plant lifespan.

It results as p = 60,234 × (0.08 × (1 + 0.08)^{20}/((1+0.08)^{20} − 1) = 6,134 USD.

This represents a first estimate of the yearly social benefit of the project's time horizon (= treatment plant lifespan).

Construction and operation and maintenance costs were adjusted in order to take local social security payments and unemployment rate into account and to remove tax effects. According to [27], labor shadow prices can be evaluated as 60% of labor market prices. The global adjusted costs are reported in Table 6 and the complete flow of the economic analysis is shown in Table 7.

Table 6. Cost estimation (shadow prices).

Cost Type	Total
Construction (USD)	61,326
Operation and maintenance (USD/year)	2750

Table 7. Economic Analysis: cost-benefit flows and economic indicators.

Year	Costs C_k (USD)	Benefits B_k (USD)	B_k-C_k (USD)
0	61,326		−61,326
1	2750	6135	3385
2	2750	6135	3385
3	2750	6135	3385
4	2750	6135	3385
5	2750	6135	3385
6	2750	6135	3385
7	2750	6135	3385
8	2750	6135	3385
9	2750	6135	3385
10	2750	6135	3385
11	2750	6135	3385
12	2750	6135	3385
13	2750	6135	3385
14	2750	6135	3385
15	2750	6135	3385
16	2750	6135	3385
17	2750	6135	3385
18	2750	6135	3385
19	2750	6135	3385
20	2750	6135	3385
NPV (USD)		−28,092	
BCR		0.682	
IRR (%)		0.1	
PBP (year)		never	

The NPV is clearly negative (−28,092 USD). This means that the judgment of the project is not favorable from an economic point of view, if social benefits are estimated through the WTP declared by resident households.

The validity of the WTP estimate depends on the level of information provided to respondents [28,29]. On one hand, unreliable estimates may occur when interviewees' information regarding the context is poor. On the other hand, "free riding" behavior can occur when the interviewee believes he can obtain personal advantages with his own answers, for example by declaring a low WTP for a public commodity, because he expects the others to pay for him.

For these reasons, to complete the economic analysis, it may be interesting to replace the estimate of a WTP-based benefit with a cost-based estimate. This can be achieved by assessing the health cost that the treatment plant is able to avoid. It is well known that if raw zootechnical farm wastewaters are directly released in a surface water body, an increment of the pollutant load occurs, in particular an increment of the microbiological load (among the different bacteria, *E. coli*). As a consequence, a direct human injection with this polluted water may lead to gastrointestinal diseases [30]. In this regard, it is estimated that in Ecuador the social cost of one case of gastrointestinal disease is, on average, 140 USD (https://www.salud.gob.ec/consejo-nacional-de-fijacion-y-revision-de-precios-de-medicamentos/). How many diseases have to be avoided in order to guarantee sanitary benefits at a level that is sufficient to make feasible the investment? In this context, Figure 6 shows that the construction of the treatment plant becomes economically favorable if the annual benefits reach the value of 8998 USD, equivalent to the social cost of 64.26 cases of gastroenteritis (8998/140 = 64.26). If the decision-maker believes that the plant could really achieve this effectiveness level, he could decide to run the public project, financing it through tax revenues.

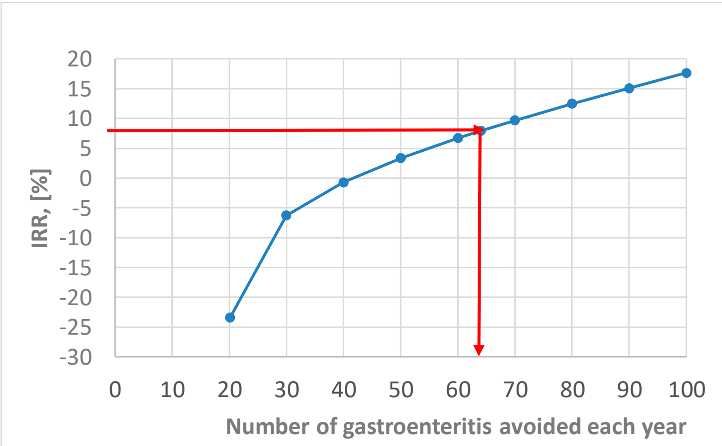

Figure 6. Sensitivity analysis based on the health efficacy of the project.

3.4. Focus on the Collected Data for the Evaluation of the WTP

A presentation of the collected data for the evaluation of the WTP is reported here to provide an explanation of how the respondents' replies were collected and processed.

The main characteristics of the respondents in terms of gender, age, education level, job title and yearly family income are summarized in Table 8: 44% of the respondents are female and the largest percentage is between 31 and 60 years old (357 people out of 510). 42% of the surveyed population completed high school studies and 34% received a primary school certificate; there are very few people with a university degree (12% of respondents). Most of the interviewed people have a full-time job (35%) or work part-time (30%); the categories of students and housewives both represent 13%. The remaining people are retired (6%) or unemployed (2%). Finally, referring to the annual family income, 85% of the respondents have an annual family income ≤12,000 USD but this never exceeds 50,000 USD.

Table 8. General survey results.

Description	Number	%	Description	Number	%
Gender			*Job title*		
Male	284	56	Full time worker	180	35
Female	226	44	Part time worker	154	30
Age			Retired	32	6
≤30	85	17	Unemployed	10	2
31–40	130	25	Student	66	13
41–50	139	27	Housewife	68	13
51–60	88	17			
61–70	58	11	*Annual family income*		
>70	10	2	≤ 12000	432	85
Education level			12.000 to 20.000	57	11
None	60	12	20.001 to 30.000	18	4
Primary	174	34	30.001 to 40.000	2	0
Secondary	215	42	40.001 to 50.000	1	0
University	61	12	>50.000	0	0

On the basis of the replies collected during the 510 interviews, it was found that residents in the area under study are well aware that the quality of the environment and water, as well as human health and wellbeing would increase if zootechnical farm wastewaters were subject to an adequate treatment train. Moreover, for 56% of them environmental protection is an issue of high importance, for 32% of medium importance and for 72% of them, the community should take care of the environment.

It emerged that 78% of the interviewed people do not know how constructed wetland systems work and they have never seen a natural treatment such as a lagoon or a (vertical/horizontal) subsurface flow bed. Despite this fact, they were very interested in understanding how these systems work and once it had been explained, 65% of the respondents agreed with the proposal of the construction of a treatment plant based on this technology for the zootechnical sector in the Paute region. On the other hand, 19% of the respondents disagreed with this proposal and the remaining 16% did not have a clear opinion regarding the construction of the plant. The most frequent reasons for respondents' opposition were related to the expected costs (for the plant construction and its operation and maintenance), the potential risks to human health and the potential release of bad odors.

An analysis of the relationships between the WTP and the respondents' characteristics (educational level, age, annual income, type of work and living zone) was carried out and reported in Figures 7–11. It is important to highlight that the respondent was expected to provide the WTP referring to his/her family.

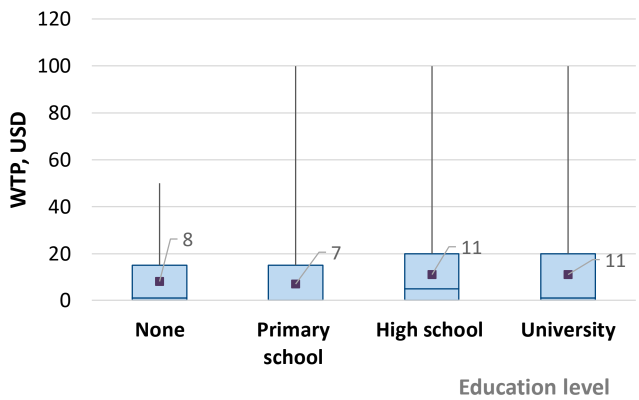

Figure 7. Box-plots for the correlation between WTP and education level of the respondents (the bullet represents the average value for each category).

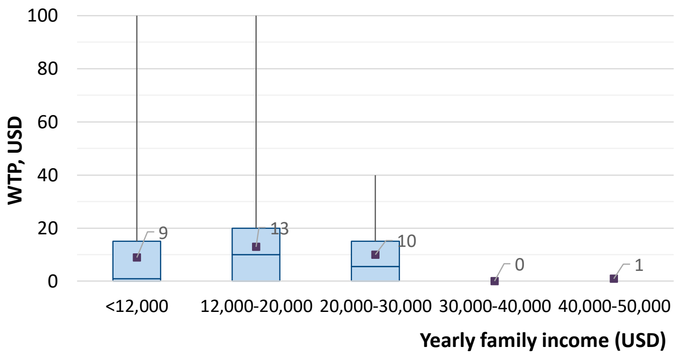

Figure 8. Box-plots for the correlation between WTP and the annual family income level of the respondents (the bullets represent the average value for each category).

Figure 9. Box-plots for the correlation between WTP and the job type of the respondents (the bullet represents the average value for each category).

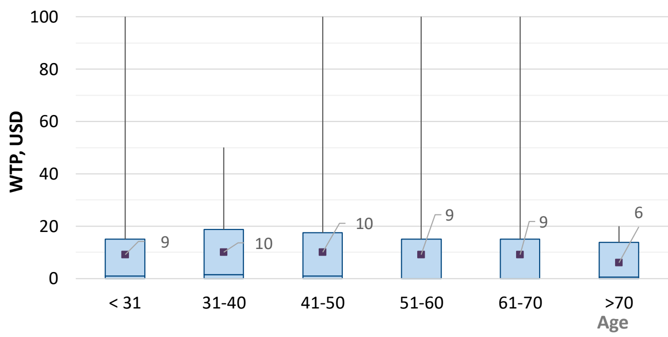

Figure 10. Box-plots for the correlation between WTP and the age class of the respondents (the bullet represents the average value for each category).

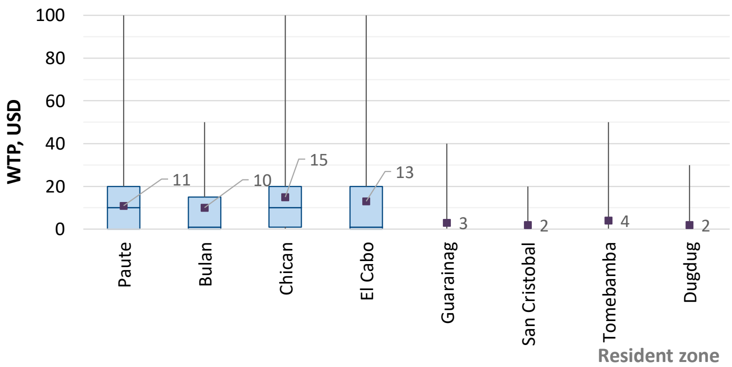

Figure 11. Box-plots for the correlation between WTP and the resident zone of the respondents (the bullet represents the average value for each category).

It was found that the higher the educational level of a respondent, the higher his/her WTP. Interviewees with a university degree exhibited an average WTP of 11 USD, whereas those with a primary education certificate have an average WTP of 7 USD, confirming the same trend already found and discussed in other similar studies, among them [14].

People with an annual income between 12,001 and 20,000 USD exhibited an average WTP of 13 USD (Figure 8). The family income class with the greatest number of respondents was the first (<12,000 USD) with an average WTP of 9 USD. No correlation was found between annual income and WTP, as was the case in another study [31]. The main concern exhibited in Figure 8 is that the highest WTP (100 USD) was related to the lowest family income groups: 4 respondents in the first class and one in the second.

With regard to job type (Figure 9), the corresponding average WTP varies between 7 and 10 USD, whereas the variation ranges differed according to the job, with full time workers and housewives showing the widest range (0–100 USD) and unemployed people showing the smallest (0–20 USD).

The highest average WTP was found for full- and part-time workers, as well as for students. The latter category highlights the significance of students' educational level. The highest WTP values were found for four full-time workers and one housewife.

People from 31 to 50 years old are those with the highest average WTP (Figure 10), confirming the tendency already found in other studies referring to wastewater treatment plants [32]. With regard to this case study, this trend can be explained by the fact that they correspond to a working population mainly involved in the zootechnical sector and which considers the construction of a treatment train for the effluent from this sector to be a priority. The highest WTP values were found for two respondents in the range 41–50 and for one in the other three classes (< 31; 51–60, 61–70).

The analysis of the WTP distribution with regard to the eight resident zones shows that the highest WTP values refer to the Chican region (Figure 11) where the treatment plant should be constructed and the adjacent zones (Paute, Bulán and El Cabo). The reason could be the fact that the respondents resident in these areas are well aware of the problems connected with the direct release of untreated zootechnical farm wastewaters and are mainly interested in the construction of a treatment plant aiming to improve the quality of the place where they spend most of their day.

Respondents resident in Chicán have an average WTP of 15 USD, whereas the population in Dugdug (the most distant zone) has an average WTP of 2 USD. The highest values of WTP were found in Paute (1 respondent), in Chican (2) and in El Cabo (2).

4. Conclusions

This study presented and discussed a treatment train for a zootechnical farm wastewater in the case of a medium size farm which is quite common in Ecuador. It also showed the financial and economic feasibility of this project by considering the construction, operation and maintenance costs of the treatment system and a financial and socio-environmental benefit.

The selected treatments were a combination of well-known natural and conventional technologies and fit well with the characteristics of the area of study. The financial analysis was based on the monetary inflows and outflows of the farm, calculated on the basis of market prices. It indicated that the construction of the plant is not feasible from a private point of view.

The economic analysis compared the investment costs, calculated on the basis of shadow prices, with the social benefits linked to the improvements brought by the new plant. If the social benefits were assessed on the basis of local families' willingness to pay, the project was not socially feasible. On the basis of these findings, the decision maker should not sustain the project.

However, a sensitivity analysis, carried out on benefits, showed that if the project were able to avoid at least 64 cases of gastroenteritis every year, the consequent saving of health costs could justify construction of the plant from the point of view of political decision makers. It should be noted that the health benefits are not limited to the reduction of diseases, but also extend to the elimination of unpleasant odors caused by the release of untreated effluents. A monetary assessment of these additional benefits would increase the economic viability of the project.

This study could be amplified, analyzing environmental, agricultural and other social benefits in greater depth as well comparing collected results with those obtained with other kinds of treatment trains including conventional technologies (anaerobic digestors, upflow anaerobic sludge banket) requiring higher investment and operational costs and more qualified personnel.

Author Contributions: For this research article all of the authors contributed extensively to the work. V.P. supervised this research, V.P. and G.Z. coordinated the different tasks in the economic feasibility of the study, E.C.A.S. carried out the interviews and all three authors contributed to the data analysis and the writing and revision of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

BCR	Benefit Cost Ratio
CBA	Cost-Benefit Analysis
CVM	Contingent Valuation Method
CW	Constructed wetland
HSSF	Horizontal subsurface flow
IRR	Internal rate of return
NPV	Net present value
O&M	Operation and maintenance
PBP	Payback period
VSSF	Vertical subsurface flow
WTP	Willingness to Pay
WWTP	Wastewater treatment plant

References

1. World Bank Group. *Reducing Inequalities in Water Supply, Sanitation, and Hygiene in the Era of the Sustainable Development Goals*; World Bank Group: Washington, DC, USA, 2017.
2. Metcalf & Eddy. *Wastewater Engineering, Treatment, Disposal, Reuse*; McGraw-Hill: New York, NY, USA, 2006.
3. Kadlec, R.H.; Wallace, S.D. *Treatment Wetlands*, 2nd ed.; CRC Taylor and Francis Group: Boca Raton, FL, USA, 2008.
4. Verlicchi, P.; Al Aukidy, M.; Galletti, A.; Zambello, E.; Zanni, G.; Masotti, L. A project of reuse of reclaimed wastewater in the Po Valley, Italy: Polishing sequence and cost benefit analysis. *J. Hydrol.* **2012**, *432–433*, 127–136. [CrossRef]
5. Masotti, L.; Verlicchi, P. *Depurazione Delle Acque Di Piccole Comunità, Tecniche Naturali E Tecniche Impiantistiche*; Hoepli: Milano, Italy, 2005. (In Italian)
6. INEC (Instituto Nacional de Estadísticas y Censos del Ecuador). *Encuesta Nacional de Empleo, Desempleo y Subempleo*; Instituto Nacional de Estadísticas y Censos del Ecuador: Quito, Ecuador, 2018.
7. Gobierno Autónomo Descentralizado del Cantón Paute. *Plan de Desarrollo y Ordenamiento Territorial del Cantón Paute*; Gobierno Autónomo Descentralizado del Cantón Paute: Paute, Ecuador, 2014.
8. Salazar, D.; Cuichán, M.; Ballesteros, C.; Márquez, J.; Orbe, D. *Encuesta de Superficie y Producción Agropecuaria Continua ESPAC 2017*; Instituto Nacional de Estadísticas y Censos del Ecuador INEC: Quito, Ecuador, 2017.
9. PDOT (Plan de Desarrollo y Ordenamiento Territorial del cantón Paute). 2015. Available online: http://app.sni.gob.ec/sni-link/sni/PORTAL_SNI/data_sigad_plus/sigadplusdiagnostico/0160000510001_DIAGN%C3%93STICO_GADM_PAUTE%20FINAL_12-03-2015_09-21-02.pdf (accessed on 28 February 2019).

10. Ministerio del Ambiente del Ecuador, Texto Unificado de Legislacion Secundaria de Medio Ambiente, Quito-Ecuador. 2003. Available online: http://www.ambiente.gob.ec/wp-content/uploads/downloads/2015/06/Texto-Unificado-de-Legislacion-Secundaria-del-Ministerio-del-Ambiente.pdf (accessed on 28 February 2019).
11. American Public Health Association. *APHA Standard Methods for the Examination of Water and Wastewater*, 23rd ed.; American Public Health Association: Washington, DC, USA, 2017.
12. Rojas Bustamante, O. Manual Básico Para Medir Caudales. 2006. Available online: http://www.bivica.org/upload/medir-caudales-manual.pdf (accessed on 28 February 2019).
13. European Commission. Guide to Cost-Benefit Analysis of Investment Projects: Economic Appraisal Tool for Cohesion Policy 2014–2020. Available online: https://ec.europa.eu/inea/sites/inea/files/cba_guide_cohesion_policy.pdf (accessed on 28 February 2019).
14. Verlicchi, P.; Al Aukidy, M.; Zanni, G. Willingness to pay for recreational benefits evaluation in a wastewater reuse project. Analysis of a case study. *Water* **2018**, *10*, 922.
15. Welsh, M.P.; Poe, G.L. Elicitation effects in contingent valuation: Comparisons to a multiple bounded discrete choice approach. *J. Environ. Econ. Manag.* **1998**, *36*, 170–185. [CrossRef]
16. Pearce, D.W.; Turner, R.K. *Economics of Natural Resources and the Environment*; The John Hopkins University Press: Baltimore, MD, USA, 1980.
17. Alp, E.; Yetiş, Ü. Application of the contingent valuation method in a developing country: A case study of the yusufeli dam in Northeast Turkey. *Water Sci. Technol.* **2010**, *62*, 99–105. [CrossRef]
18. Tudela-Mamani, J.W. Willingness to pay for improvements in wastewater treatment: Application of the contingent valuation method in Puno, Peru. *Revista Chapingo Serie Ciencias Forestales y del Ambiente* **2017**, *23*, 191–213. [CrossRef]
19. Irwin, N.; Irwin, E.; Marti, J.; Aracena, P. Constructed wetlands for water quality improvements: Benefit transfer analysis from Ohio. *J. Environ. Manag.* **2018**, *206*, 1063–1071. [CrossRef]
20. Guerrini, A.; Vigolo, V.; Romano, G.; Testa, F. Levers supporting tariff growth for water services: Evidence from a contingent valuation analysis. *J. Environ. Manag.* **2018**, *207*, 23–31. [CrossRef]
21. Alcon, F.; Pedrero, F.; Martin-Ortega, J.; Arcas, N.; Alarcon, J.J.; de Miguel, M.D. The non-market value of reclaimed wastewater for use in agriculture: A contingent valuation approach. *Span. J. Agric. Res.* **2010**, *8*, 187–196. [CrossRef]
22. Chui, T.F.M.; Ngai, W.Y. Willingness to pay for sustainable drainage systems in a highly urbanised city: A contingent valuation study in Hong Kong. *Water Environ. J.* **2016**, *30*, 62–69. [CrossRef]
23. INEC (Instituto Nacional de Estadísticas y Censos del Ecuador). *Censo de Población y Vivienda del Ecuador*; Instituto Nacional de Estadísticas y Censos del Ecuador: Quito, Ecuador, 2010.
24. Sacoto, E.C.A. A Treatment Train Based on Constructed Wetlands for the Treatment of Zootechnical Wastewater. A Study Case in Paute-Ecuador. Ph.D. Thesis, University of Ferrara, Ferrara, Italy, 2019.
25. Masi, F.; Rizzo, A.; Martinuzzi, N.; Wallace, S.D.; Van Oirschot, D.; Salazzari, P.; Meers, E.; Bresciani, R. Up-flow anaerobic sludge blanket and aerated constructed wetlands for swine wastewater treatment: A pilot study. *Water Sci. Technol.* **2017**, *76*, 134–146. [CrossRef] [PubMed]
26. Asamblea Nacional Republica del Ecuador, Ley Orgánica de Recursos Hídricos, Usos Y Aprovechamiento Del Agua, Segundo Suplemento- Registro Oficial No 305-6/8/2014. Available online: http://extwprlegs1.fao.org/docs/pdf/ecu165480.pdf (accessed on 28 February 2019).
27. Londero, E.H.; Cervini, H. *Shadow-Prices for Project Appraisal: Theory and Practice*; Edward Elgar: Cheltenham, UK, 2003.
28. Mitchell, R.C.; Carson, R.T. *Using Surveys to Value Public Goods: The Contingent Valuation Method, Resources for the Future*; RFF Press: New York, NY, USA, 1989.
29. Bergstrom, J.C.; Stoll, J.R.; Titre, J.P.; Wright, V.L. Economic value of wetlands-based recreation. *Ecol. Econ.* **1990**, *2*, 129–147. [CrossRef]
30. Donovan, E.; Unice, K.; Roberts, J.D.; Harris, M.; Finley, B. Risk of gastrointestinal disease associated with exposure to pathogens in the water of the lower passaic river. *Appl. Environ. Microbiol.* **2008**, *74*, 994–1003. [CrossRef] [PubMed]

31. De Simone Souza, H.H.; Paulo, P.; Boncz, M.A. A constructed wetland system for residential greywater reuse: Economic feasibility of and willingness to pay for. *Desalin. Wat. Treat.* **2017**, *91*, 336–348. [CrossRef]
32. Lizinski, T.; Wroblewska, A.; Rauba, K. Application of CVM method in the evaluation of flood control and water and sewage management projects. *J. Water Land Dev.* **2015**, *24*, 41–49. [CrossRef]