A Quality Evaluation of Wastewater in Quito's Metropolitan Area for Environmental Sustainability

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Abstract

The demand for water in recent years has increased rapidly, it is for this reason that wastewater recycling becomes an integral part of its management. This promotes the conservation of freshwater supplies with high quality standards. In addition, pollutants and cost in their final treatment are reduced. It is in this way that this research reports the quality of a domestic residual effluent from residential washing machines. Treated gray water can be used as a substitute for fresh water for non-potable end uses, helping to overcome water shortages worldwide. The effluent studied has an average outlet temperature of 21 °C and a pH of 7.4. By means of analytical techniques the alkalinity and acidity of this were determined (228.20 mg/L CO3; 1651.80 mg/L HCO3 and 0.00053 mg/L). The total hardness is 395.09 mg/L (369.44 mg/L Mg and 25.65 mg/L Ca). When making a comparison with the parameters allowed for sewage discharges and water quality values for irrigation, in order to possible reuse. The effluent evaluated has an extremely high alkalinity, this causes precipitation of calcium and magnesium ions such as carbonates. This effluent cannot be discharged directly to the sewer without prior treatment. Like it cannot be reused as irrigation water in crops because of its hardness and nitrate content.

Keywords

Assessment system, Water quality, Total hardness, Residual water, Quito

1. Introduction

Wastewater recycling is becoming an integral part of water demand management, as it promotes the conservation of high-quality freshwater supplies and potentially reduces pollutants in the environment and overall costs. Waste water is defined as "water of varied composition from domestic, industrial, commercial, agricultural, livestock or other use, whether public or private and which for this reason has suffered degradation in its original quality" [1].

The proportion of water used that is required to be of the highest quality is small. This implies that most of the demands within the process scheme are for lower grade water, allowing water reuse from one application to another. An example is in the domestic environment where the reuse of gray water for toilets can be achieved with little or no treatment [2, 3]. Gray wastewater is defined as wastewater without toilet entry, meaning that it corresponds

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to wastewater produced in bathtubs, showers, sinks, washing machines and kitchen sinks, in homes, building offices, schools, etc. The total fraction of gray wastewater has been estimated at approximately 75% of the combined residential wastewater [4].

A review of current water demands in large buildings revealed that not only gray sewage from bathrooms, but also washing machines, sewage or stormwater is necessary to provide enough recycled water for non-potable uses [5, 6].

Treated gray water can be used as a substitute for fresh water for non-potable end uses, helping to reduce freshwater consumption and overcome water shortages worldwide [7]. Studies have shown that 3050% of drinking water can be saved by recycling gray water for garden irrigation and toilet flushing [8]. Outdoor applications for gray wastewater could be lawn irrigation on university campuses, sports fields, cemeteries, and parks, as well as in the home garden [9, 10].

The risk of contamination of the soil and of the receiving waters due to the content of different pollutants is another issue that has been raised in relation to infiltration and irrigation with gray wastewater. Christova et al, stated that infiltration and irrigation can lead to high concentrations of detergents in the soil and some plants may suffer due to alkaline water [11].

There are several problems related to the reuse of untreated gray wastewater. The risk of disease spread, due to exposure to microorganisms in water, will be a crucial point if water is to be reused, for example, for washing the toilet or watering. In addition to the risk that microorganisms in the water will spread in the form of aerosols that will be generated as the toilets are discharged [12].

The WHO guidelines for treated wastewater used for irrigation of agricultural crops and public sports fields limit fecal coliforms to <1000/100 mL and nematodes to <1/L [13]. In Ecuador there are regulations in force regarding the quality of water for irrigation, as well as for discharges to the public sewer system [1]. Table 1 shows the discharge limits to the public sewer system. For this reason, it is necessary to carry out an analysis of the gray wastewater within the DMQ to determine the quality of the water and after that, establish the need or not for a treatment for reuse in various fields such as its reuse for irrigation.

Table 2 shows the parameters of the guide levels of water quality for irrigation. Despite the advantages of gray water recycling registered throughout the world, there is no international standard to control the quality of gray water for reuse [14].

Apart from simple diversion systems, gray water recycling systems can consist of a complex combination of treatments [15, 16]. Before entering the main treatment process, raw gray water normally enters a screening process, followed by sedimentation to remove coarse particles and suspended solids. Subsequently, the gray water is directed to the main treatment process that involves biological, chemical, physical, or extensive treatment units, before disinfection [14]. Figure 1 illustrates the flow chart of a typical gray water treatment system.

1.1. Metropolitan District of Quito

The DMQ occupied only the Historic Center, however, in the mid-19th century the city grew and demanded more resources (27 900 to 2 239 191 habitants). Occupying this way from 639 ha to 37 400 ha [17]. The DMQ has 32 urban parishes and 33 suburban and rural parishes. In Figure

Table 1
Discharge limits to the public sewer system [1]

Parameters	Units	Maximum permissible limit
Acids or bases that can cause contamination, explosive or flammable substances.	mg/L	Zero
Aluminum	mg/L	5.00
Barium	mg/L	5.00
Carbonates	mg/L	0.10
Active chlorine	mg/L	0.50
DBO5	mg/L	250.00
DQO	mg/L	500.00
Total manganese	mg/L	10.00
Silver	mg/L	0.50
Lead	mg/L	0.50
Total solids	mg/L	1600.00
Temperature	°C	<40.00
Vanadium	mg/L	5.00
Zinc	mg/L	10.00
Hydrogen potential		5-9
Organochlorine Compounds	mg/L	0.05
Carbon tetrachloride	mg/L	1.00
Carbon sulphide	mg/L	1.00
Sulfates	mg/L	400,00
Sulphides	mg/L	1,00

2 you can differentiate all your parishes; some of them have extensions that are identified as ecological protection zones [18].

The DMQ is located in the western part of the Ecuadorian Andes at an altitude of around 2800 meters above sea level. The climate of the city has two marked seasons, one rainy and one dry that includes the months of June, July and August. The annual rainfall is distributed in the south of the city of about 1400 mm / year and in the north about 70 mm/year [19].

Quito is the second most populous city in Ecuador, according to INEC it has 2 576 287 inhabitants and in 2021 it will have 2 723 665. Figure 4 shows population growth over the years. There may be a population growth of around 20.80 % due to migratory movements. Emphasis is placed on accelerated unplanned urbanization resulting in greater environmental degradation and greater waste generation [20].

The DMQ's drinking water supply is carried out through integrated systems, complemented by independent systems in rural areas. The safe flow of water available in the sources currently used in Quito is 8.6 m/s, which come from basins with supplementary hydrological cycles.

All water sources and catchments for Quito are managed by the Metropolitan Public Water

Table 2
Parameters of the guide levels of water quality for irrigation [1]

POTENTIAL PROBLEM	UNITS	*RESTRICTION DEGREE			
		None	Light	Moderate	Severe
Salinity SDT	mg/L	450	450	2000	>2000
Infiltration RAS = 0 − 3 y CE RAS = 3 − 6 y CE RAS = 6 − 12 y CE RAS = 12 − 20 y CE RAS = 20 − 40 y CE		0.7 1.2 1.9 2.9 5.0	0.7 1.2 1.9 2.9 5.0	0.2 0.3 0.5 1.3 2.9	<0.2 <0.3 <0.5 <1.3 <2.9
Specific ion toxicity - Sodium: RAS Surface irrigation Aspersion -Clorides Surface irrigation Aspersion -Boron	meq/L meq/L meq/L mg/L	3.0 3.0 4.0 3.0 0.7	3.0 3.0 4.0 3.0 0.7	9.0 10.0 3.0	>9.0 >10.0 >3.0
Miscellaneous effects - Nitrogen (N-NO3) - Bicarbonate (HCO3)	mg/L meq/L	5.0 1.5	5.0 1.5	30.0 8.5	>30.0 >8.5
pH	Normal range	6.5 − 8.4			

and Sanitation Company "EPMAPS" which captures, transports, purifies, stores and distributes the water to be used throughout the DMQ. The daily water consumption per person is 170 L. The water used in the homes of the District is evacuated by internal pipes of the homes with connection to the public sewer system that go directly to the Machángara River.

The riverbed of this river is severely contaminated due to the indiscriminate discharges of wastewater generated by the city of Quito and that are discharged into the river basin without any previous treatment [22].

For its treatment there is an installed capacity of 8.5 m3/s, of which 7.3 m3/s are currently produced. The coverage of the potable water and sewerage service is currently estimated at 98.50 % and 92.27 % respectively [23]. The DMQ discharges 5.5 m of wastewater every second, says Luis Antonio Gómez, an engineer at the Metropolitan Public Company for Drinking Water and Sanitation (EPMAPS). It ends at the Machángara, Monjas, San Pedro and Guayllabamba rivers.

1.1.1. Main rivers of the DMQ

There are 14 river basins that are part of the Metropolitan District of Quito:

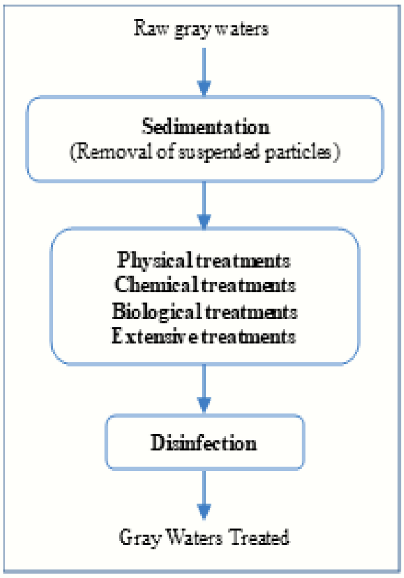

Figure 1: Gray water treatment scheme [11]

- San Pedro, is formed in the south-eastern part of Quito and its main tributary is the Pita River, receiver of the wastewater from the valleys of Los Chillos and Cumbayá-Tumbaco. Its waters are used for hydroelectric power generation.
- Machángara, is formed from several streams located south of Quito and the Batán stream located to the north center.
- Guayllabamba, take this name at the confluence of the Machángara and San Pedro rivers.
- Nuns, crosses the northwestern part of Quito collecting its wastewater, flows into the Guayllabamba River.
- Pita, Pachijal, Intag, Chiche, Guambi, Uravia, Alambi, Mindo, El Cinto-Saloya, and Coyago, are used as irrigation water and once treated with residential drinking water, as shown in Figure 5. In Table 3 shows the length of the main watersheds of the DMQ.

1.1.2. Uses of DMQ effluents

According to Fichtner, studies conducted on DMQ effluents are not suitable for the following activities [24]:

- Defense of aquatic and wildlife

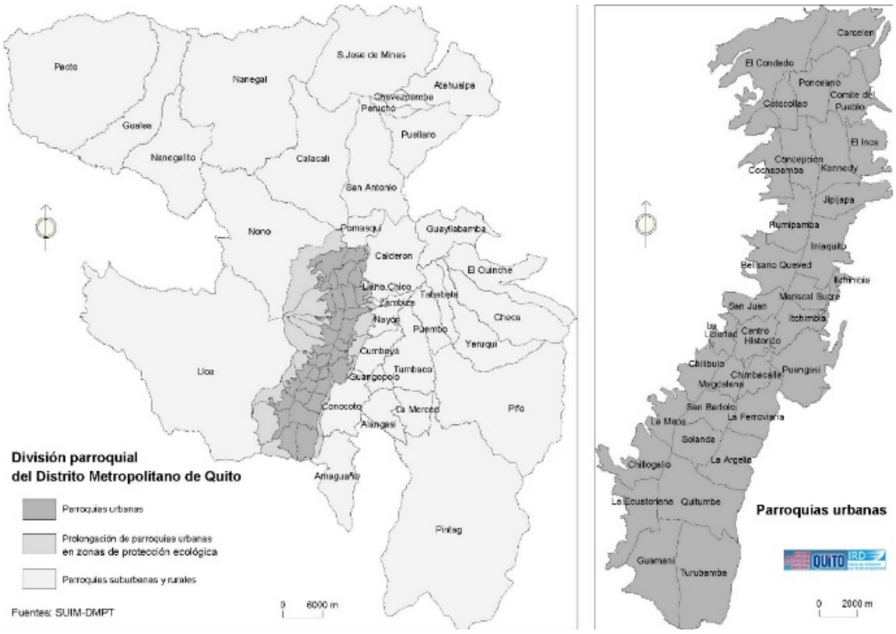

Figure 2: Quito Parish Division of the Metropolitan District of Quito [21]

Table 3
Length of the main rivers of the DMQ [24]

River	Length (km)
Machángara	22.5
Monjas	24.5
San Pedro	53.9
Guayllabamba	175.3

- Human consumption and domestic use
- Agricultural use
- Livestock use
- Recreational purposes (secondary contact)
- Aesthetic use
- Industrial use

Table 4 details the concessionary uses of water from the Quito rivers. SENAGUA, establishes that the water of the Machángara River is under irrigation with 54 concessions whose

Table 4
Water concessions of the DMQ rivers [25]

River	Concessioned Uses	Number of Concessions	Total Concessioned Flow (L/s)
Machángara	Trough	4	1.67
	Hydroelectricity	1	2 100.00
	Industry	1	98.00
	Irrigation	54	922.49
	Subtotal	61	3 133.31
Monjas	Trough	1	0.01
	Hydroelectricity	3	4 535.00
	Industry	2	71.50
	Irrigation	53	839.87
	Thermal	1	2.50
	Domestic use	3	8.03
	Subtotal	63	5 456.91
San Pedro	Trough	23	8.17
	Drinking water	1	70.00
	Hydroelectricity	4	5 365.00
	Industry	7	1 536.70
	Fish farming	2	6.00
	Irrigation	95	3 138.86
	Domestic use	13	1 321.07
	Subtotal	145	11 445.80
Guayllabamba	Industry	1	12.06
	Irrigation	38	662.26
	Domestic use	1	0.04
	Subtotal	40	674.36

flow is 922.49 L/s and one granted for the Nayón hydroelectric power station. As for the Guayllabamba 38 river, intended for irrigation with a total flow of 662.26 L/s. The Monjas River has 53 concessions for irrigation and 3 for hydroelectric plants with a total flow of 4 535 L/s.

1.2. Machangara River

The Machángara is the most important river in Quito and receives 75 % of the city's wastewater, in addition to large amounts of garbage and debris, which also pollute it [25]. Figure 6 shows the Machángara River in the Las Cuadras park sector.

The Machángara River is called the Guayllabamba River at the confluence with the San Pedro River, and downstream it receives the Chiche, Guambi and Uravía rivers.

Figure 7 shows the Machángara River from its formation (UTM X: 774 939, Y: 9 970 201) to its mouth on the Guayllabamba River (X: 792 555, Y: 9 992 864). Its extension is around 36 km.

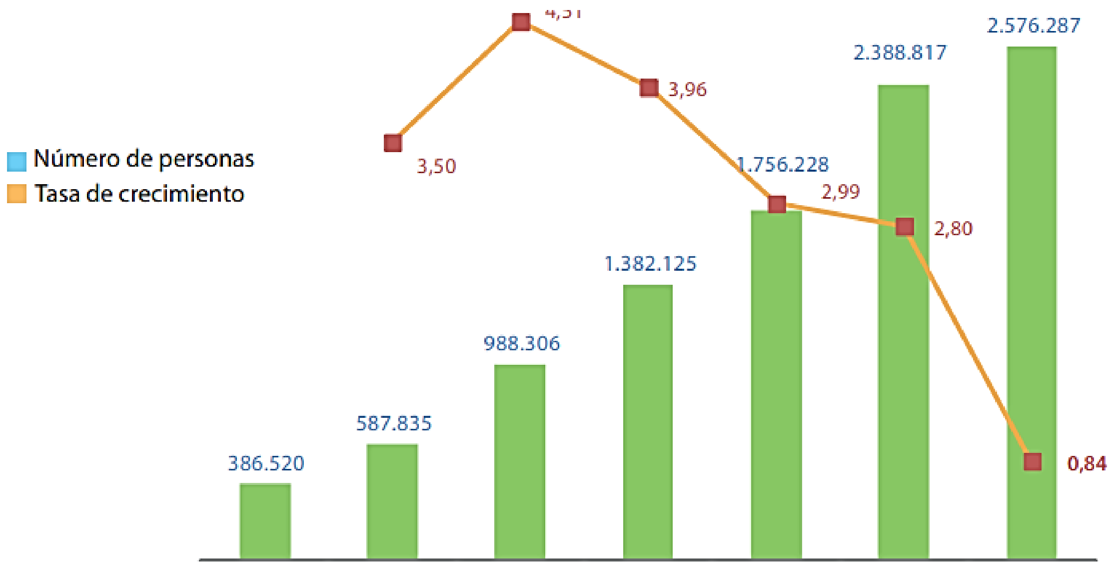

Figure 3: Population distribution of the Metropolitan District of Quito [20]

2. Methodology

2.1. Effluent Collection

3 L of the effluents from the laundry were collected after completing their rinse and spin process in different sectors of the city of Quito. For the characterization of the samples, they were stored in plastic bottles previously washed with distilled water (avoid interference or contamination).

2.2. Characterization of the effluent

After 24 h, the collected effluent was filtered in order to eliminate possible solid residues that interfere with the determination of the quality parameters by analytical methods.

2.2.1. Determination of temperature and pH

The temperature was measured in situ at the outlet of the washer discharge, with a Multi-Thermometer brand digital thermometer (-50 °C to +300 °C). The hydrogen potential was determined in 3 samples of the effluent with a Martini instruments Mi 805 pH meter.

2.2.2. Determination of acidity

To 100 mL of sample was added 4 drops of phenolphthalein indicator; and titrated with a 0.02 N NaOH solution to the point of turn (faint pink). With the volume spent, the concentration of acid present in the effluent was determined (Equation 1).

$$C_a x V_a = C_b x V_b \ (1)$$

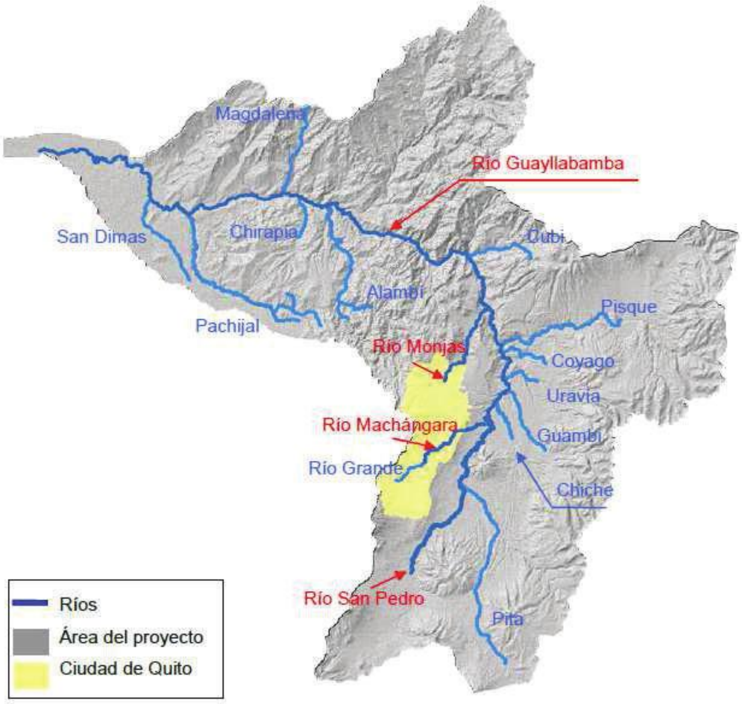

Figure 4: Hydrographic basins of the Metropolitan District of Quito [18]

Where:
C_a : unknown concentration in the effluent (eq/L).
V_a : sample volume to holder.
C_b : known concentration of titrant (eq/L).
V_b : volume spent on the degree.

2.2.3. Alkalinity Determination

100 mL of titrated effluent was taken, and 4 drops of phenolphthalein was added. The holder was carried out with 0.02 N H_2SO_4 until the indicator changed to colorless (1 min). Consider the volume of acid spent and then Equation 1 was used to determine the concentration present in the effluent. In the previous sample add 3 drops of methyl orange drops indicator. It was titled again until the indicator changed to pink it lasted for 1 min. The volume spent was measured.

2.2.4. Determination of total hardness

50 mL of effluent sample was taken in an erlenmeyer with a capacity of 250 mL, 5 mL of ammonia buffer solution and 0.1 g of black eriochrome T indicator were added. The holder was used with 0.01 M of EDTA until reaching the turning point which remained for 1 min. More titrant was added and there was no color change.

To determine the calcium hardness, 50 mL of the water sample was placed in an Erlenmeyer of 250 mL capacity, then 4 N NaOH and 0.1 g of murexida were added. Finally, it was titrated with 0.01 M of EDTA to the turning point (violet coloration) lasting time 1 min.

2.2.5. Determination of chloride ions

For the measurement of chloride ions, 100 mL of sample was measured and 5 drops of K2CrO4 indicator (vigorous stirring) were added. Then 0.05 N AgNO3 was added by means of a burette until a color change occurred. The corresponding calculations were performed with the consumption of standardized solution.

* For all trials, 3 repetitions were performed, and an average was obtained with the volume spent on each degree.

2.2.6. Determination of nitrate and sulfate ions

For the measurement of nitrates and sulfates, a HACH DR 5000 spectrophotometer was used. For this purpose, white readings were made with deionized water, with the help of envelopes for nitrate and sulfate detection tests, 25 mL aliquots of the effluent were taken respectively, and stirred them vigorously. Finally, it was run on the equipment specified above, obtaining immediate results for its subsequent tabulation.

2.3. Determination of the water quality index (WQI)

To determine the effluent quality index, the analytical results obtained from the collected and analyzed samples were described. Table 5 shows the water quality assessment from the WQI. The water quality index is determined with the use of certain parameters:

- Dissolved oxygen
- Fecal coliforms
- pH
- Biochemical Oxygen Demand
- Nitrates
- Phosphates
- Temperature deviation
- Total solids

Table 5
Quality assessment from the WQI

WQI	Quality Evaluation
91-100	Excellent water quality
71-90	Good water quality
51-70	Average water quality
26-50	Fair water quality
0-25	Poor water quality

Table 6
Characteristics of domestic residual effluent

Parameter	Value	Units
Temperature	21	° C
pH	7.4	-
Alkalinity	5,27 x10	eq/L
Carbonates	228.20	mg/L
Bicarbonates	1 651.80	mg/L

3. Results and Discussion

3.1. Effluent characterization

Table 6. shows the characteristics of a domestic residual effluent from residential washing machines. The effluent discharge temperature is approximately 21 °C, it should be noted that temperature variations affect the solubility of salts and gases present. An important point in relation to temperature is the microbiological behavior in the environment.

In addition, it presented a basic pH corresponding to 7.4. This indicates that the residual water can present carbonates and bicarbonates.

As for acidity and alkalinity, it has a value of 5.27×10^{-4}; and 228.198 mg/L (carbonates); 1 651.80 mg/L (bicarbonates) respectively. These results affirm the previous consideration, that at a basic pH there is the presence of both carbohydrates and bicarbonates.

As for the total hardness, the calcium hardness and the one characterized by magnesium can be observed in Table 7.

The carbonate and bicarbonate ions can be combined with the calcium and magnesium present and generate calcium carbonate or magnesium carbonate. This could make it difficult to use this effluent as irrigation water. Equations 2 and 3 show the reactions that occur in the presence of calcium and magnesium in the water. In addition, Figure 8 emphasizes the formation of calcium carbonate in waters with high hardness.

$$H^{+?+HCO_3 \leftrightarrow H_2CO_3(2)}$$

Table 7
Total hardness of domestic residual effluent

Hardness	Value	Units
Magnesium	369.44	mg/L
Calcium	25.65	mg/L
Total	**395.09**	**mg/L**

Figure 5: Machángara River Basin

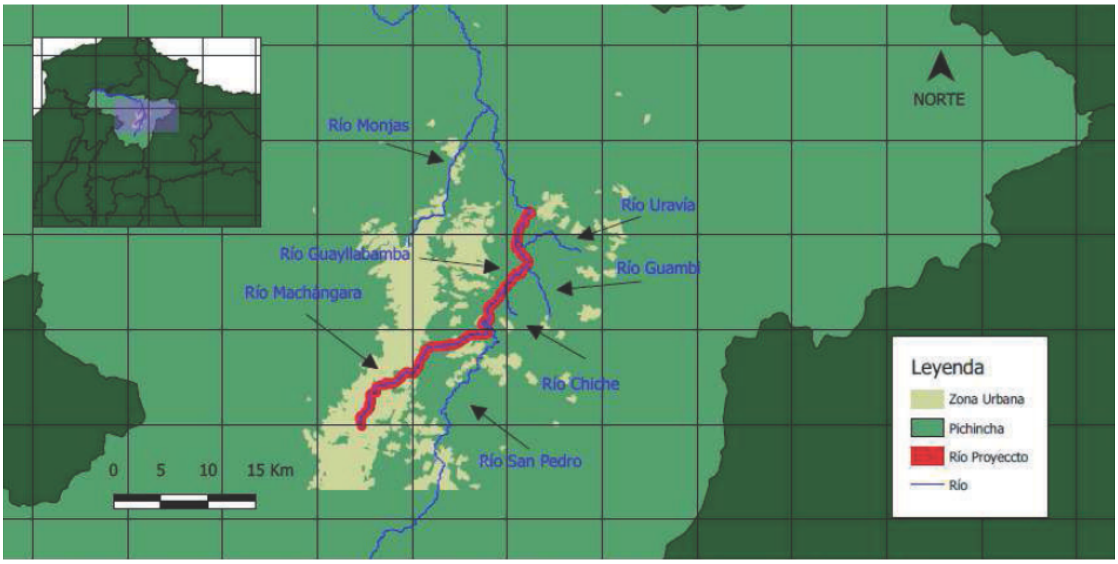

Figure 6: Location of the Machángara River Basin

$$CO_3^{-2} + Ca^{+2} \leftrightarrow CaCO_3 \; (3)$$

Another analysis of high importance is knowing the amount of chlorides, nitrates and sulfates present in the residual effluents that are going to be discharged into the sewer. This serves to know whether to give a subsequent treatment before downloading. As if you want to reuse it in another medium. Table 8 indicates the amount of average chlorides, nitrates and sulfates

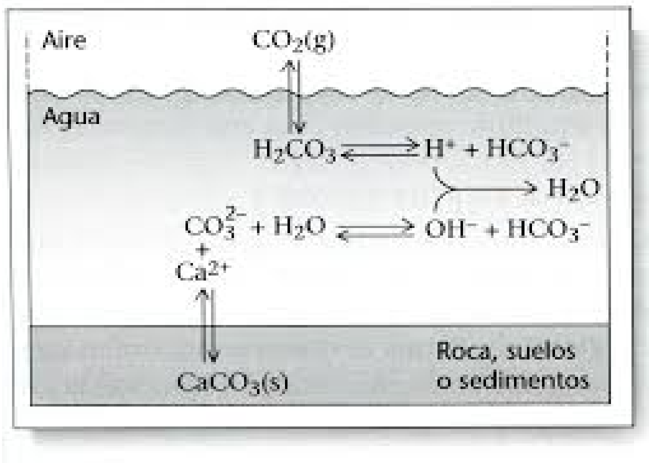

Figure 7: Scheme of the presence of carbonates and calcium in water.

Table 8
Ions present in the domestic residual effluent

Ions	Value	Units
Chlorides	17.73	mg/L
Nitrates	0.21	mg/L
Sulfates	**0.92**	**mg/L**

present in 5 samples of wastewater from residential washing machines.

The presence of chlorides in natural, residential or residual waters is evident, since these inorganic ions are necessary for the purification of these. That is, the study effluent in addition to containing chloride ions used in the purification process is increased by adding surfactants, detergents and softeners for washing. In relation to nitrates and sulfates, the present concentration is very low, this may be due to the dragging of ions along pipes, to the contact with organic matter present in textile fabrics, or dirt adhered to clothing.

3.2. Comparison of the effluent characteristics with the permitted values for effluent discharges to the public sewer system

The maximum permissible load highlights each of the parameters that can be accepted in the discharge of a receiving body; in this case, all the residual effluent generated from residential washing machines ends up in the sewer system. Some parameters obtained from the evaluated effluent were compared with the Ecuadorian discharge standards as shown in Table 9.

With the results described above the residual effluent obtained from the discharge of the washing machine for domestic use, the presence of carbonates exceeds the maximum permissible limit by more than 100 %. The temperature, pH, nitrates and sulfates are well below the maximum allowable limit. The excessive presence of carbonates can cause the precipitation of

Table 9
Comparison of the characteristics of domestic wastewater with the parameters allowed for discharges according to the Ecuadorian standard [26]

Parameter	Domestic residual effluent	Maximum permissible limit	Units
Temperature	21	<40	°C
pH	7.40	4 - 9	-
Carbonates	**114.10**	**0.1**	mg/L
Nitrates	0.21	10	mg/L
Sulfates	0.92	400	mg/L

Table 10
Comparison of the characteristics of domestic wastewater with water quality values for irrigation.

Parameter	Domestic residual effluent	Permissible limit	Units
pH	7.4	6.5 – 8.4	-
Chlorides	0.50	3.0 – 4.0	meq/L
Nitrates	0.21	5 - 30	mg/L
Bicarbonates	54.16	1.5 – 8.5	meq/L

ions and this in turn the incrustation of salts in the pipes.

3.3. Comparison of effluent characteristics with water quality values for irrigation

In Table 10, the quality of the residual effluent is compared with the water quality values for irrigation. When comparing these values, they indicate that the effluent obtained is not suitable for use as irrigation water. The effluent evaluated is outside the ranges established within the permissible limits that would consider this water to be used as irrigation water. The presence of chloride ions greatly affects the sensitivity of crops. Nitrates can have positive or negative effects on the use of the effluent, their use in crops with nitrite and nitrate ion deficiency could be considered.

The parameter that prevents the use of this effluent without prior treatment is the presence of bicarbonates and the hardness it presents.

3.4. Determination of the water quality index (WQI)

Table 11 shows the Water Quality index of the Machángara River as it crosses the entire DMQ.

According to Table 11 the water quality of the Machángara River is a “fair” water which means that it is below having a good quality. The WQI obtained by weighting indicates that it is a “very poor” water, of poor quality and suitable for human consumption.

Table 11
Water quality index of the Machángara WQI river

Variable	Measure	Unit	Ii	Wi	Ii Wi	Ii ^Wi
DO	50	%	**85**	0.17	14.45	2.13
Fecal coliforms	1.62 E7	#/100 mL	2	0.15	0.30	1.11
pH	7.8	-	90	0.12	10.8	1.72
DBO5	211	mg/L	2	0.10	0.2	1.07
NO3	21	mg/L	30	0.10	3.0	1.41
PO4	7	mg/L	5	0.10	0.5	1.17
Temperature	8.7	°C	20	0.10	2.0	1.35
Turbidity	70	JTU	30	0.08	2.4	1.31
Total solids	396	mg/L	50	0.08	4	1.37
WQI					**37.65**	**12.64**

Table 12
Water quality of the Machángara River [27]

Wastewater quality	Unit	TULSMA Standard	Planning Horizon			Acceptance
			2020	2030	2045	
DBO5	mg/L	30	211	237	277	Fails
DQO	mg/L	2 000	522	585	684	Complies
TSS	mg/L	100	281	315	368	Fails
SVS	mg/L	200	159	179	209	Complies
as N	mg/L	10	21	24	28	Fails
NTK	mg/L	30	39	44	51	Fails
FT	mg/L	50	7	7	7	Complies
Fecal coliforms	#/100 mL	130	1.62 E7	1.53 E7	1.39 E7	Fails

3.5. Water quality of the Machángara River according to Ecuadorian regulations

Regarding the quality and loads of the wastewater corresponding to a projection to 2020, 2030 and 2045 of the Machángara River when crossing the entire city of Quito, they were compared with the TULSMA standard, indicating what is evidenced in Table 12.

According to the results obtained from the water quality analysis, it can be evidenced that there is a breach of parameters with the maximum permissible limits both with Municipal Ordinance 0404 for water discharge and in the Unified Text of Secondary Environmental Legislation [1].

4. Conclusions

The domestic residual effluent is discharged at 21 °C and has a basic pH of 7.4. In addition, an alkalinity of 1651.80 mg/L.

The total hardness presented is 395.09 mg/L; of which 369.44 mg/L corresponds to the concentration of magnesium and 25.65 mg/L to the calcium hardness. Extremely high alkalinity causes precipitation of calcium and magnesium ions as carbonates of the respective ions.

As present ions there is the presence of: 17.73 mg/L of chlorides; 0.21 mg/L of nitrates and 0.92 mg/L of sulfates.

The evaluated wastewater exceeds the maximum permissible limit, there must be a pretreatment before discharge to the sewer. The presence of carbonate and bicarbonate ions can cause fouling in pipes and other wastewater transport systems.

The effluent obtained should not be reused for crop irrigation because it has 54.16 meq/L of bicarbonates. The concentration exceeds 6 times the allowable value according to the standard.

The water quality index of the Machángara River indicates that it is water of poor quality and is not suitable for human consumption (WQI = 12.64).

The Machángara River fails to comply with the maximum permissible limits with both Municipal Ordinance 0404 for water discharge and the Unified Text of Secondary Environmental Legislation.

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