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Artículo de Investigación

WATER QUALITY OF THE WASTEWATER TREATMENT PLANT OF THE CITY OF JIPIJAPA, ECUADOR

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ABSTRACT

Due to the accelerated population growth, the excessive concentration in urban areas and climate changes, water is increasingly scarce. Currently, more than 2 billion people lack access to drinking water and the demand for water is expected to increase by almost a third by the year 2050. Faced with this situation, it is then imperative to save water. One way to save water is by recycling and reusing drainage water and urban wastewater, but these should be suitable for use and this information is obtained by analyzing its quality. The objective of this work was to determine the physical-chemical and bacteriological parameters that define the quality of the water from the wastewater treatment plant of Jipijapa, Ecuador. To do this, water samples from the plant were analyzed and the results obtained were compared with the values established by the current laws of Ecuador for an adequate use of treated water. It is concluded that the operations that were followed in the wastewater treatment plant of the city of Jipijapa, at the time of sampling, were not completely effective, which limited, or prevented their reuse.

Keywords: water quality, water purification, wastewater treatment, environmental modeling.

CALIDAD DEL AGUA DE LA PLANTA DE TRATAMIENTO DE AGUAS RESIDUALES DE LA CIUDAD DE JIPIJAPA, ECUADOR

RESUMEN

Debido al crecimiento acelerado de la población, a la excesiva concentración en zonas urbanas y a los cambios climáticos, el agua es cada vez más escasa. En la actualidad más de 2.000 millones de personas carecen de acceso al agua potable y se prevé que la demanda de agua aumente en casi un tercio para el año 2050. Ante esta situación, se hace entonces imperativo el ahorro del agua. Una forma de ahorrar agua es reciclando y reutilizando las aguas de drenaje y aguas residuales urbanas, pero estas deben ser adecuadas para su uso y esta información se obtiene al analizar su calidad. El objetivo del presente trabajo fue determinar los parámetros físico-químicos y bacteriológicos que definen la calidad del agua procedente de la planta de tratamiento de aguas residuales de Jipijapa, provincia de Manabí, Ecuador. Para ello se tomaron muestras de aguas las cuales fueron analizadas siguiendo los estándares internacionales. Los resultados obtenidos se compararon con los valores que establece la legislación ecuatoriana vigente para un uso adecuado del agua tratada. Se concluye que las operaciones o procesos que se siguieron en la planta de tratamiento de aguas residuales de la ciudad de Jipijapa, al momento del muestreo, no fueron del todo eficaces, lo que limitó, o impidió, su reúso.

Palabras clave: calidad del agua, purificación del agua, tratamiento de aguas servidas, modelo ambiental.

QUALIDADE DA ÁGUA DA USINA DE TRATAMENTO DE ÁGUAS RESIDUAIS DA CIDADE DE JIPIJAPA, EQUADOR

RESUMO

Devido ao crescimento acelerado da população, à concentração excessiva em áreas urbanas e às mudanças climáticas, a água é cada vez mais escassa. Atualmente, mais de 2 bilhões de pessoas não têm acesso a água potável e a demanda por água poderia aumentar em quase um terço para o ano 2050. Diante dessa situação, é imperativo economizar a água. Uma maneira de economizá-la é reciclando e reutilizando tanto a água de drenagem, como as águas residuais urbanas. Não obstante, elas devem ser adequadas para ser aptas para o uso e essas informações são obtidas mediante análise de sua qualidade. O objetivo do presente trabalho foi determinar os parâmetros físico-químicos e bacteriológicos que definem a qualidade da água proveniente da estação de tratamento de águas residuárias de Jipijapa, província de Manabí, no Equador. Para este fim, amostras de água foram obtidas da estação de tratamento, que foram analisadas de acordo com os padrões internacionais. Os resultados obtidos foram comparados com os valores estabelecidos pela atual legislação equatoriana para um uso adequado da água tratada. Conclui-se que as operações ou processos que realizados na estação de tratamento de águas residuais da cidade de Jipijapa não são totalmente eficazes, o que limita, ou impede, a sua reutilização.

Palavras-chave: qualidade da água, purificação de água, tratamento de esgoto, modelo ambiental.

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1. INTRODUCTION

Looking for solutions to the current and future water crisis, the so-called Sustainable Development Goals (SDGs) have been proposed for the year 2030 in which the sustainable management of water is key to its achievement, especially Goal 6: Guarantee availability of water and its sustainable management and sanitation for all (Comisión Económica para América Latina y el Caribe [CEPAL], 2018). However, it is a well-known fact that, due to population explosion, urbanization and, probably, to climatic changes, water is increasingly scarce and its use must be prioritized for primary uses. Water scarcity, which "takes place when demand exceeds the supply of fresh water in a given area" (Food and Agriculture Organization of the United Nations [FAO], 2013) is a relative concept and dynamic, but it is also a social construction: all its causes are related to human intervention in the water cycle (FAO, 2013).

Due to the rapid growth of the world's population, the demand for water is expected to increase by almost one third by the year 2050 (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2018) and that 25% of the world's population will live in countries affected by chronic and repeated shortages of fresh water (CEPAL, 2018) . Faced with a pattern of accelerated consumption, the growing deterioration of the environment and the impacts of climate change, it is then imperative to save water. One way to save water is to recycle and reuse drainage water and urban wastewater, which is becoming increasingly important in many parts of the world, especially in areas with scarce water. To be reused wastewater must be previously treated in order to avoid risks to public health, mainly in regard to its microbiological characteristics. The quality of the reused water depends on the sector or infrastructure that receives it; among them is the urban one, for example for irrigation of public parks, the industrial one, especially in the refrigeration systems and the agricultural in the irrigation of crops.

The quality criteria for the reuse of wastewater are established in the guidelines of the World Health Organization (WHO) and, in general, the countries that have a regulation on the reuse of wastewater have taken as reference the guidelines of WHO and the Food and Agriculture Organization of the United Nations (FAO) in relation to maximum permissible limits of certain substances.

1.1. Wastewater treatment plants

Water after its use, either after covering the basic needs of the human being or those emitted as liquid waste, will be contaminated in one way or another. If it has been used for agricultural purposes it will contain pesticides, fertilizers and salts; if its use has been municipal, it carries human, pharmaceutical and detergent wastes; power plants discharge water that is at high temperatures. Of all of them, the industrial sector contributes with chemical pollutants and organic waste (Raffo & Ruiz, 2014). All wastewater must be treated, both to protect public health and to preserve the environment.

Although the production of municipal wastewater is not always monitored and published on a regular basis, it is estimated that the percentage of municipal wastewater that is subjected to treatment is very low. This is an "evil" that afflicts not only Ecuador, but the entire Latin American and Caribbean region, where the planned use of treated wastewater is an exception, not the rule. This is due to low levels of environmental awareness, high level of income, lack of political priorities and the fact that the treatment plants installed do not work adequately due to overload or operation and maintenance problems. In the Latin American and Caribbean region there is an average installed capacity to treat more than 40% of the municipal wastewater generated (FAO, 2017). However, most of the wastewater is discharged into the sea without being used, or it reaches the watercourses and is reused downstream indirectly in irrigated agriculture, which poses serious risks to the health of the people and the environment.

As a national strategy for drinking water and sanitation, the government of Ecuador will be investing, for the period 2015-2024, US $ 4.9 billion in works that will allow the treatment of all the wastewater of the ten main urban areas of Ecuador (Secretaría del Agua, 2017). Some of these works are already in operation, such as the wastewater treatment plant (WWTP) Quitumbe south of Quito which has the capacity to treat a flow of 100 L/s of wastewater (Metropolitan Public Company of Drinking Water and Sanitation [EPMAPS], 2017). At the beginning of 2017, the construction of the WWTP Las Esclusas, located south of Guayaquil, which will treat 100% of the wastewater collected in the southern sector of the city until the year 2050 began [Gobierno Autónomo Descentralizado Municipal de Guayaquil [GAD] Guayaquil, 2017). Since 1999, Cuenca, the third largest city in the country, has the WWTP Ucubamba which treats 95% of wastewater from the city; other city, such as Tena, has, since November 2015, the most advanced wastewater treatment plant in the Amazon region of Ecuador (Davis, Gutiérrez & Serrano, 2016).

Before establishing the use, or reuse, that can be given to water, it is essential to determine a series of physical-chemical and biological parameters, by using standardized methods, in order to know if the value of these parameters is within the range established by legislation valid for the required use in order to guarantee the safe use of the treated wastewater, as well as for the management of environmental quality, specific regulations are available where the parameters to be analyzed and the acceptable limits of them are established.

According to the use that will be given to water, the Ecuadorian law defines quality criteria for those waters destined for human consumption and domestic use prior to its purification; water for the preservation of aquatic and wild life in cool or warm fresh water and in marine and estuarine waters;

water for agricultural irrigation; water for livestock use; waters for recreational purposes and waters for aesthetic use. These criteria are established in **Tables 1 to 7** of the Environmental Quality and Effluent Discharge Standard: Water Resources, from the Unified Text of Secondary Legislation of Environment (TULSMA) of Ecuador (Ministerio del Ambiente [MA], 2015). Likewise, it establishes general norms of discharge of effluents, both to the sewerage system and to the bodies of water and permissible limits, dispositions and prohibitions for discharge of effluents to the sewage system and to a body of water or receiver. These limits are tabulated in **Tables 8** and **9** of the TULSMA (MA, 2015).

The Jipijapa canton is located in the southern part of the Province of Manabí in Ecuador. The coverage in drinking water in the city of Jipijapa, which is the largest population within the canton of the same name, is 90% of the urban area; the remaining 10% of the population, located in the periphery of the city, lacks this resource so they are supplied by tanker trucks.

Water availability, particularly scarcity, is influenced by water quality (UNESCO, 2018). Thus, the improvement of water quality allows its reuse. Jipijapa has a wastewater treatment plant which has been in operation since October 2004; it was designed to have a useful life of 20 years and so that after water treatment these could be used to irrigate crops, which would benefit the farmers in the area.

All environmental legislation, in particular the Ecuadorian legislation, establishes limit values or acceptable ranges for the use or reuse of water. The present work is intended to determine the quality of the water released from the Jipijapa WWTP and if it complies with national standards to be reused.

2. MATERIALS AND METHODS

To determine the quality of the water from the wastewater treatment plant (WWTP) of Jipijapa, province of Manabí, two (02) water samples were taken for physical-chemical analysis; they were collected on August 20, 2016, in the dry season of the year. A sample was collected near the entrance of the plant (M1) and the other near the exit point of the plant (M2). The sampling points were set according to the opinion of a specialist of the WWTP. The samples were collected in polyethylene bottles of 1 L capacity. Sampling, transport and conservation of the samples was carried out according to the recommendations of the American Public Health Association (APHA), and the analysis was carried out in the laboratories of Industrial Products and Services C. LTDA. from the city of Guayaquil. The physical determinations performed were pH, settleable solids, total suspended solids (TSS) and temperature. The chemical determinations were presence of Zn, Ni, Pb, Hg, hexavalent chromium Cr^{+6} and Cd metals, chemical oxygen demand (COD), biochemical oxygen demand (BOD5) and organochlorine and organophosphorus compounds, while microbiological analysis was used to determine coliforms, fecal coliforms, salmonellas and staphylococcus.

3. RESULTS AND DISCUSSION

Wastewater is characterized by its physical, chemical and biological composition and its possible reuse depends on the values presented by these parameters in order to determine if they meet the limitations required by current legislation for proper use. **Table 1** shows the physical-chemical parameters determined for the water samples taken at two points (M1 and M2) of the Jipijapa wastewater treatment plant, with an expanded U uncertainty with a coverage factor of 2 (confidence level: 95.45%).

Table 1. Physical-chemical parameters of the water obtained from the Jipijapa wastewater treatment plant.

Parameter (Unit)	Result		U K=2±	Analysis method
	M1	M2		
Potential of Hydrogen (pH)	8.1	8.1	0.2	SM 4500 H^+B
Temperature (°C)	26.1	26.3	2.5	SM 2550 B
Sedimentable solids (mL/L)	<1.0	<1.0	80%	SM 2540 F
Total Suspended Solids; TSS (mg/L)	130	164	10%	EPA 160.2
Biochemical Oxygen Demand; BDO_5 (mg/L)	166	140	20%	SM 5210 B
Chemical Oxygen Demand; COD (mg/L)	365	297	31%	EPA 410.4
Oils and fats (mg/L)	4.9	3.3	11%	EPA 413.2
Zinc; Zn (mg/L)	<0.20	<0.20	15%	SM 3111 B
Nickel; Ni (mg/L)	<0.10	<0.10	20%	SM 3111 B
Lead; Pb (mg/L)	<0.20	<0.20	40%	EPA 420.1
Cadmium; Cd (mg/L)	<0.01	<0.01	12%	SM 3111B
Hexavalent Chromium; Cr^{6+} (mg/L)	<0.10	<0.10	------	SM 3500 Cr B
Organochlorine compounds (mg/L)	<0.02	<0.02	------	EPA 8081
Organophosphorus compounds (mg/L)	<0.02	<0.02	------	EPA 8141
Mercury; Hg (mg/L)	<0.002	<0.002	------	SM 3141 C

All environmental legislations establish limit values or acceptable ranges for the use or reuse of waters. **Table 2** shows the average results for the physical-chemical and bacteriological parameters obtained from the water samples of the Jipijapa WWTP and the limit values for these parameters established in the Ecuadorian environmental legislation for the different water uses.

3.1. Water pH analysis

The pH value obtained in both sampling points indicates that the water is slightly alkaline and is between the normal values for urban spills and between the acceptable values, established in the Ecuadorian legislation, for waters destined to the irrigation of vegetables, legumes consumed in crude, cereals, and tree crops (Registro Oficial, 2015). However, the type of crop to irrigate depends on the other physical-chemical values.

Table 2. Average results for the physical-chemical and bacteriological parameters obtained from the water samples from the Jipijapa WWTP and the limit values for these parameters established in the Ecuadorian environmental legislation for the different water uses (MA, 2015).

Parameter (Unit)		**Results of this work**	**Maximum limits allowed**				
			Agricultural use in irrigation (1)	**Livestock use (2)**	**Recreational purposes (3)**	**Discharge of water effluents**	
						Fresch Water	**Sea water**
Potential of Hydrogen (pH)		8.1	6.5-8.4	6-9	6.5 - 8.5	6-9	6-9
Temperature (°C)		26.2				<35	<35
Sedimentable Solids (mL/L)		<1.0				1.0	1.0
Total Suspended Solids (mg/L)		147	Absence	Absence	Absence	100	100
Biochemical Oxygen Demand: BOD_5 (mg/L)		153	<10	<10	<10	100	100
Chemical Oxygen Demand: COD (mg/L)		331				160	160
Oil and fats (mg/L)		4.1	Absence		0.3	30.0	30.0
Metals	Zn (mg/L)	<0.20	2.0	5.0	0.0	5.0	10.0
	Ni (mg/L)	<0.10	0.2	0.5	0.0	2.0	2.0
	Pb (mg/L)	<0.20	0.05	0.05	0.0	0.2	0.5
	Cd (mg/L)	<0.01	0.05	0.05	0.0	0.02	0.2
	Cr^{6+} (mg/L)	<0.10	0.1	1.0	0.0	0.5	0.5
	Hg (mg/L)	<0.002	0.001	0.01	0.0	0.005	0.01
Organochlorine compounds (mg/L)		<0.02	0.2	0.2	0.2	0.05	0.05
Organophosphorus compounds (mg/L)		<0.02	0.1	0.1	0.1	0.1	0.1
Coliforms (NMP/mL)		240	10	50	20^{a}. 40^{b}	100	100
Fecal coliforms (NMP/mL)		150	<10	<10	2^{a}. 10^{b}	20	20
S*almonellas* sp		Absence					
Staphylococcus sp (UFC/mL)		0					

1) Water for agricultural use is that used for the irrigation of crops and other related or complementary activities established by the competent bodies. The use of wastewater for irrigation is prohibited except if it is done with treated wastewater and that meet the quality levels established in the Standard.
(2) Waters for livestock use are those used for the animal trough, as well as other related and complementary activities established by the competent agencies.
(3) The use of water for recreational purposes is understood as the use in which there is: a) primary contact, such as in swimming and diving, including medicinal baths and b) secondary contact such as in water sports and fishing.

3.2. Temperature

In general, the physical-chemical and biological parameters that characterize water are related to each other. For example, temperature affects both the biological activity and the amount of dissolved gases in the wastewater. The temperature values in the wastewater will depend on the area and time of year in which the measurement is made. In the case of the samples obtained, its average temperature was 26.2 ° C. This value is in correspondence with the average temperature of the time of year in which the sample was taken; is lower than the limit established in the TULSMA (MA, 2015) for discharges to a body of fresh water and is included in the optimal temperature range for the development of bacterial activity which is between 25 ºC and 35 ºC (Ramos & Zúñiga, 2008).

3.3. Solids

Sedimentable solids are the cause of turbidity because they produce light scattering through the water sample and could damage irrigation engines and obstruct irrigation devices if the water is reused for irrigation; for this reason the water must have very low turbidity and few solids in suspension (FAO, 2017). In the case of the samples taken, the values of total suspended solids (TSS) obtained were 130 mg/L and 164 mg/L (average 147 mg/L) and less than 1.0 mg/L for the settleable solids. The TSS average exceeds the maximum limit allowed by the current legislation for discharge of effluents to bodies of fresh water, while in the case of settleable solids the value obtained is lower than the established limit (see **table 2**).

3.4. Organic matter: Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

For M1 sampling point, the values of 166 mg/L and 365 mg/L were obtained for BOD_5 and COD respectively, while for M2 sampling point were obtained the values 140 mg/L and 297 mg/L for BOD5 and COD respectively (average BOD_5 153 mg/L, average COD 331 mg/L). The values obtained for both parameters are higher than the limit values established in the standard (see **table 2**).

A parameter generally used to identify the biodegradability of the different types of water, is the COD/BOD_5 ratio, which allows to determine how much of the COD (organic and inorganic matter contained in the sample) of a water is susceptible to being purified by the microorganisms in 5 days (BOD_5) (Ardila, Reyes, Arriola & Hernández, 2012). In our case, there is a COD/BOD_5 ratio = 2.17 (average). This value is similar, within the limits of the experimental error, to the value of 2.08 that would be obtained when it is not completely degradable matter, as is the case, precisely, of urban waste water in which 80% of the COD it produces degradable organic matter and the remaining 20% is produced by inerts (Ronzano & Dapena, 2015). The value indicates that most of the COD (organic and inorganic matter) present in the water can be oxidized biochemically (Ardila *et al*., 2012).

3.5. Oils and fats

Another parameter used to measure organic pollutants is the concentration of oils and fats from food residues or industrial processes (automobiles, lubricants, etc.). Oils and fats are difficult to metabolize by bacteria and float forming films in water that can interfere with aerobic and anaerobic processes if they occur in excessive amounts. In the case of the samples studied, the values measured at both sampling points (4.1 mg/L, average) are well below the maximum limit established for effluent discharges.

3.6. Heavy metals

Heavy metals are those chemical elements with high density, toxic in low concentrations and that in some of their forms can represent a serious environmental problem. The metals analyzed in this work: cadmium (Cd), mercury (Hg), lead (Pb), zinc (Zn), nickel (Ni) and chromium (Cr) are considered among the most interesting due to their high toxicity relative to water quality (Singh, Kumar, Agrawal & Marshal, 2010).

3.6.1. Cd, Hg and Pb

Some studies that evaluate the contamination of heavy metals in food, meat and milk, have found that cadmium, mercury and lead are three of the elements that due to their impact on health and concentration must be carefully evaluated and monitored (Reyes, Vergara, Torres, Díaz & González, 2016). **Table 3** shows the maximum permissible limits for heavy metals concentration established by the European Union and FAO according to the type of use that is given to water (Reyes *et al.,* 2016).

Table 3. Maximum permissible limits of concentration of heavy metals (Hg Cd and Pb) in water for different uses established by the European Union and FAO. The values marked with an asterisk (*) correspond to those established in the Ecuadorian environmental legislation (MA, 2015).

Water use	Unit	Hg	Cd	Pb
Human consumption	mg/L	0.001	0.01	0.05
Discharges into seas and estuaries		0.0001	0.05	0.01
Agricultural use		0.001	0.01	0.05
Livestock use		0.01	0.05	0.05
Discharges into bodies of freshwater		0.005*	0.02*	0.2*

As can be seen in **table 3**, in the case of discharge of effluents to freshwater bodies, the values established in the Ecuadorian legislation are, with the exception of the Cd, notably higher than those indicated by the FAO. However, the values obtained in the sampling points of the Jipijapa WWTP for these three metals are lower than the maximum permissible limits in Ecuador for discharges in freshwater courses.

3.6.2. Zn, Ni, Cr^{6+}

The problem of heavy metals such as nickel (Ni) and zinc (Zn), particularly present in the wastewater used for irrigation, lies mainly in that they can be accumulated in agricultural soils. They are dangerous because of their non-biodegradable character, the toxicity they exert on different crops and their bioavailability. Normally, low chromium (Cr) levels are present in the environment. Under normal conditions, exposure to Cr does not represent any toxicological risk. Trivalent chromium Cr^{3+}, or Cr (III), is an essential nutrient and is relatively non-toxic to humans. However, hexavalent chromium, Cr^{6+} or Cr (VI), is a danger to the health of humans. The values obtained for these metals at the sampling points are <0.20 mg/L, <0.10 mg/L and <0.10 mg/L, for Zn, Ni and Cr^{6+}, respectively. The results obtained for the metals under study, except Pb, allows discarding them as possible contaminants, since these elements have concentrations lower than the values established in the Ecuadorian legislation for different water uses (see **table 2**).

3.7. Pollutants pesticides: Organochlorine and organophosphorus compounds

Organochlorine pesticides represented by dichlorodiphenyltrichloroethane (DDT) and hexachlorocyclohexane (HCH) are compounds that were widely used worldwide for agricultural activities and for the control of disease vectors such as malaria (Waliszewski *et al.,* 2013). They have a relatively acute toxicity and accumulate in adipose tissue with long-term adverse effects. On the other hand, organophosphorus compounds have multiple applications and utilities, including agriculture as pesticides. They have chemical characteristics similar to each other and are inhibitors of the enzyme acetylcholinesterase. Around 75% of organophosphates are metabolized to measurable substances, called dialkyl phosphates that are not considered toxic, but they are markers of exposure to organophosphates (Ríos & Solari, 2013). In the case of analysis, the values obtained for these compounds were, for both compounds, <0.02 mg/L, lower than the maximum limits established in the Ecuadorian standard.

3.8. Bacteriological contamination

Considering its reuse, the presence of coliform bacteria in the wastewater represents a potential threat to public health, to aquatic flora and fauna, and this could indicate that disinfection was not sufficient to eliminate all pathogenic organisms associated with the waste of human and animal origin. Table 4 shows the results obtained from the bacteriological analysis of wastewater from the Jipijapa WWTP.

In the analyzed samples, there is no presence of the genus Salmonella or Staphylococcus; however, compared with the values shown in **table 2**, the coliform levels obtained are very high and indicate the presence of bacteria of fecal origin.

Table 4. Bacteriological analysis of a water sample from the Jipijapa WWTP.

Parameters (Unit)	Result
Coliforms (NMP/mL)	240
Fecal Coliforms (NMP/mL)	150
S*almonellas* sp	Absence
Staphylococcus sp (UFC/mL)	0

4. CONCLUSIONS

The availability of water, particularly scarcity, is influenced by the quality of it. Thus, an efficient treatment of wastewater allows its reuse. However, in general, the results show that the operations or processes that were followed, at the time of sampling, at the wastewater treatment plant in the city of Jipijapa, to reduce the concentration of pollutants from the discharges of wastewater, were not all effective. In particular, the presence of fecal coliform bacteria in water is an indicator of the insufficient disinfection process and also of the recent and frequent contamination of water with human and animal feces. This limits or prevents their reuse in other areas and even represents a source of contamination if they are discharged without control to the Jipijapa river.

The risk to health and limiting the reuse of wastewater treated in the WWTP comes from the excessive concentration of fecal coliforms, which could be an indicator of the presence of pathogenic microorganisms and which shows that the disinfection process in the WWTP of Jipijapa is not efficient. These values could be in correspondence with the high values shown by BOD and COD, because the high organic content favors the growth of bacteria and fungi.

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