LOGISTIC MODEL FOR PREDICTING COLIFORM GROWTH IN WASTEWATER EFFLUENT FROM THE CHAMBO RIVER (ECUADOR)

Jaime Giovanny Béjar-Suárez[A], Juan Carlos Muyulema-Allaica[B], David Geovanny Béjar Cáceres[C], Mayra Elizabeth Cáceres-Mena[D], Benito Guillermo Mendoza-Trujillo[E], Nelly Ivonne Guananga-Diaz[F]

ARTICLE INFO	ABSTRACT
	Purpose: The objective of this work is to apply a predictive model of bacterial growth to determine the concentration of total coliforms, under controlled laboratory conditions, in wastewater from the city of Riobamba that flows into the Chambo River (Ecuador). **Theoretical Framework:** Wastewater pollution is a global problem that affects water quality and public health. Population growth has a drastic impact on the contamination of water bodies, particularly in Ecuador, since most of the effluents are not adequately treated, which becomes a public health and environmental problem. For this reason, over the years, total and fecal coliforms have been used as indicators of water quality. **Design/Methodology/Approach:** The study used a mathematical modeling approach of a logistic and deterministic type, and calculated through an executable command designed in the integrated development environment (IDE) with the Visual C# programming language (logic) and the XAML design language (interface). **Findings:** The results achieved are 1) the theoretical construction of a mathematical model (logistic model) starting from a differential equation and the taking of three experimental measurements, 2) the computer construction of the bacterial growth model and 3) it has been demonstrated that there is agreement between the values obtained from the model of total coliform growth and the experimental results with a margin of error of less than 1%. **Research, Practical & Social Implications:** This information can be used by stakeholders to determine actions that could improve current conditions. **Originality/Value:** The result of this study emphasizes that the model proposed can reproduce the growth of coliforms up to a maximum growth point, it is necessary to

[A] Ph.D. in Environmental Sciences, Master's Degree in Environmental Management. Faculty of Sciences, Escuela Superior Politécnica de Chimborazo. Riobamba, Ecuador. E-mail: jbejar@espoch.edu.ec
Orcid: https://orcid.org/0000-0002-0444-2565
[B] PhD in Industrial Engineering: Industrial Design and Production Technologies. Industrial Engineering Research and Innovation Center, State University Santa Elena Peninsula. La Libertad, Ecuador.
E-mail: jmuyulema@upse.edu.ec Orcid: https://orcid.org/0000-0002-9663-8935
[C] Master's Degree in Technologies and Applications in Computer Engineering. Research and Development (R&D) Department in the Multimedia Industry, TEDIAL - Media Management Solutions, 29590. Málaga, Spain.
E-mail: davidbejar2009@gmail.com Orcid: https://orcid.org/0000-0002-7085-1877
[D] Master's Degree in Basic Mathematics, Master's in Intelligence Development and Education. Faculty of Sciences, Escuela Superior Politécnica de Chimborazo. Riobamba, Ecuador. E-mail: mcaceres@espoch.edu.ec
Orcid: https://orcid.org/0000-0001-6977-7801
[E] PhD in Hydraulic Engineering for the Environment and Territory. Faculty of Engineering, National University of Chimborazo. Riobamba, Ecuador. E-mail: bmendoza@unach.edu.ec Orcid: https://orcid.org/0000-0001-8555-8350
[F] Master of Science in Biotechnology, D. in Chemistry Specialty Organic Biochemist. Faculty of Sciences, Escuela Superior Politécnica de Chimborazo. Riobamba, Ecuador. E-mail: nguananga@espoch.edu.ec
Orcid: https://orcid.org/0000-0003-0451-7878

Intern. Journal of Profess. Bus. Review. |Miami, v. 9 | n. 1| p. 01-19 | e03654 | 2024.

1

continue with the development of the same in the stationary phase of bacterial growth and then in the decay phase.

MODELO LOGÍSTICO PARA PREVER O CRESCIMENTO DE COLIFORMES EM EFLUENTES DE ÁGUAS RESIDUAIS DO RIO CHAMBO (EQUADOR)

RESUMO
Objetivo: Este trabalho tem como objetivo aplicar um modelo preditivo de crescimento bacteriano para determinar a concentração de coliformes totais, sob condições laboratoriais controladas, em águas residuais da cidade de Riobamba que deságuam no Rio Chambo (Equador).
Referencial Teórico: A poluição das águas residuais é um problema global que afeta a qualidade da água e a saúde pública. O crescimento populacional tem um impacto drástico na poluição dos corpos d'água, especialmente no Equador, pois a maioria dos efluentes não é tratada adequadamente, o que se torna um problema de saúde pública e ambiental. Por esse motivo, os coliformes totais e fecais têm sido usados ao longo dos anos como indicadores da qualidade da água.
Desenho/Metodologia/Abordagem: Uma abordagem de modelagem matemática logística e determinística foi usada no estudo e calculada por meio de um comando executável projetado no ambiente de desenvolvimento integrado (IDE) com a linguagem de programação Visual C# (lógica) e a linguagem de design XAML (interface).
Resultados: Os resultados alcançados são: 1) a construção teórica de um modelo matemático (modelo logístico) a partir de uma equação diferencial e a realização de três medições experimentais; 2) a construção computacional do modelo de crescimento bacteriano; e 3) foi demonstrado que há concordância entre os valores obtidos do modelo de crescimento de coliformes totais e os resultados experimentais com uma margem de erro inferior a 1%.
Pesquisa, Implicações Práticas e Sociais: Essas informações podem ser usadas pelas partes interessadas para determinar ações que poderiam melhorar as condições atuais.
Originalidade/Valor: O resultado deste estudo enfatiza que o modelo proposto pode reproduzir o crescimento de coliformes até um ponto de crescimento máximo, sendo necessário mais desenvolvimento na fase estacionária do crescimento bacteriano e depois na fase de decaimento.

Palavras-chave: Água, Efluente, Modelo Logístico, Coliformes, Crescimento Bacteriano.

MODELO LOGÍSTICO PARA PREDECIR EL CRECIMIENTO DE COLIFORMES EN LAS AGUAS RESIDUALES DE UN EFLUENTE DEL RÍO CHAMBO (ECUADOR)

RESUMEN
Propósito: Este trabajo tiene por objetivo aplicar un modelo predictivo del crecimiento bacteriano para determinar la concentración de coliformes totales, bajo condiciones controladas de laboratorio, en agua residual proveniente de la ciudad de Riobamba y que desemboca en el río Chambo (Ecuador).
Estado del arte: La contaminación de las aguas residuales es un problema global que afecta a la calidad del agua y a la salud pública. El crecimiento poblacional incide drásticamente en la contaminación de los cuerpos de agua, particularmente en el Ecuador ya que la mayor cantidad de efluentes no son tratados adecuadamente, esto se convierte en un problema de salud pública y ambiental. Por esta razón a través de los años se han usado coliformes totales y fecales como indicadores de calidad de agua.
Diseño/Metodología/Enfoque: En el estudio se utilizó un enfoque de modelación matemática de tipo logístico y determinístico, y calculado a través de un comando ejecutable diseñado en el entorno de desarrollo integrado (IDE) con el lenguaje de programación (lógica) de Visual C# y el lenguaje de diseño (interfaz) XAML.
Hallazgos: Los resultados alcanzados son 1) la construcción teórica de un modelo matemático (modelo logístico) partiendo de una ecuación diferencial y la toma de tres mediciones experimentales, 2) la construcción informática del modelo de crecimiento bacteriano y 3) se ha demostrado que existe concordancia entre los valores obtenidos del modelo del crecimiento de coliformes totales y los resultados experimentales con un margen de error menor al 1%.
Investigación, Implicaciones Prácticas y Sociales: Esta información puede ser utilizada por las partes interesadas para determinar acciones que podrían mejorar las condiciones actuales.
Originalidad/Valor: El resultado de este estudio enfatiza que el modelo planteado puede reproducir el crecimiento de coliformes hasta un punto máximo de crecimiento, es necesario continuar con el desarrollo del mismo en la fase estacionaria del crecimiento bacteriano y después en la de decaimiento.

Palabras clave: Agua, Efluentes, Modelo Logístico, Coliformes, Crecimiento Bacteriano.

Intern. Journal of Profess. Bus. Review. | Miami, v. 9 | n. 1 | p. 01-19 | e03654 | 2024.

2

INTRODUCTION

Although not a new phenomenon, natural water bodies currently have pollution as a major problem (Iqbal et al., 2022; Rai et al., 2022). The freshwater system often exists as a complex network of interconnected water bodies of many types, such as rivers, lakes, ponds, wetlands, and reservoirs (Pinto & Shimakawa, 2022; Sekharan et al., 2022). Wastewater discharge is a serious problem in urban and rural areas in developing countries where financial resources are scarce (Villa-Achupallas et al., 2018). Weak or non-existent sewerage networks and wastewater treatment systems in areas contribute to the increase in bacterial contamination (Küpper et al., 2022; Sanchez et al., 2020). Industrialization, rapid population growth and urbanization are the main causes of the problem (Küpper et al., 2022; Sanchez et al., 2020). The poor quality of wastewater effluents discharged to receiving waters causes water quality degradation in interconnected water bodies (Capparelli et al., 2021; Carrillo et al., 2021), this being a constant in environmental deterioration (Ukaogo et al., 2020). Logistic modeling is an innovative tool in effluent management (Herfiantara & Famiola, 2023; Suchetana et al., 2019). Unlike other methods that require regular testing to assess water quality, logistic modeling can provide valuable information on coliform growth and help in decision making much faster and more effectively (Dzhamtyrova & Kalnishkan, 2020). The present study aimed to perform mathematical modelling using a logistic deterministic model under controlled laboratory conditions, i.e. the model depends only on the coliform growth to be studied. Although there are similar investigations where logistic models are applied to measure bacterial growth, even with modifications to the logistic model, such as Fujikawa et al., (2003) and Pinto & Shimakawa (2022), among others; in this work, the authors propose the application of a logistic model based on only three experimental measurements. To validate the model, it was applied to an effluent contaminated with waste from the city of Riobamba and industrial waste. In this sense, the bacterial growth of total coliforms in contaminated wastewater that flows into the most important river in the province of Chimborazo (Chambo River) in Ecuador is determined, as described below, using software that was developed for this purpose, in which three coliform measurements are entered at equal time intervals. The executable command delivers the results of the maximum coliform concentration, the growth curve and the concentration values according to the number of intervals defined.

Intern. Journal of Profess. Bus. Review. | Miami, v. 9 | n. 1 | p. 01-19 | e03654 | 2024.

3

THEORETICAL REFERENTIAL

A logistic model is a mathematical model used to describe the growth of biological organisms (Suchetana et al., 2019). These models are used to predict the growth of bacteria in a specific environment (Razanamahandry et al., 2018). Al the same describes the growth rate of a bacterial population over time. Based on the amount of available nutrients and temperature, the model predicts the growth rate and eventually the total number of bacteria present in the water (Łobacz et al., 2022).

Coliforms are a group of bacteria found naturally in human and animal intestines (Habib et al., 2023). The presence of coliforms in water indicates possible fecal contamination and a risk to public health (Pras & Mamane, 2023). Researchers have found that the amount of coliforms in water is influenced by a variety of factors such as temperature, salinity, and the amount of dissolved oxygen (He et al., 2023).

Numerous studies have been carried out to determine the water quality of aquatic systems using pollution indicator bacteria, such as total and faecal coliforms, better known as thermotolerant bacteria (González-Zeas et al., 2022; Sanchez et al., 2020; Vanacker et al., 2016); as anthropogenic action increases near aquatic ecosystems, there is a possibility that the presence of this type of bacteria will increase (Andrée et al., 2021; Iqbal et al., 2022; Sotomayor et al., 2020). Thus, current World Health Organisation (WHO) guidelines recommend the use of Escherichia coli or thermotolerant coliforms as indicators of water quality (Gruber et al., 2014; Sila, 2019). Mathematical and statistical models have been developed to predict bacterial growth (Zwietering et al., 1990). Several growth models are found in the literature, such as the models of Gompertz (1825); Richards (1959); Stannard et al., (1985); Polese et al., (2011); Bhatia et al., (Bhatia et al., 2011); Erbas et al., (2014); Kim et al., (Kim et al., 2018) and the logistic model Razanamahandry et al., (Razanamahandry et al., 2018); Chen et al., (2020) and others by Choi & Seo (2018); Sreenivas et al., (2020); Łobacz et al., (2022). Models are abstractions of reality; in fact, they can all be considered essential to capture different scales of a phenomenon and to better understand the dynamics of an ecosystem (Hadi, 2023; Pinto & Shimakawa, 2022; A Succurro et al., 2017; Antonella Succurro & Ebenhöh, 2018). On the one hand, there are models with deterministic approaches (based on differential equations and stoichiometric models with constraints) and, on the other hand, models with stochastic approaches (associated with a cumulative distribution function and a probability density function). In this research, a deterministic approach is assumed, based on the minimum number

Intern. Journal of Profess. Bus. Review. | Miami, v. 9 | n. 1 | p. 01-19 | e03654 | 2024.

4

of data required for the construction of the growth model, but with a reduced margin of error with respect to the real values.

METHODOLOGY

For the construction of the logistic model of bacterial growth, a phase must be considered in which the specific growth rate starts at a value of zero and then accelerates to a maximum value in a certain period of time, represented by growth curves containing a final phase in which an asymptote is reached (Zwietering et al., 1990).

To describe such a curve and to reduce the measured data to a limited number of parameters, the authors propose a logistic model with a deterministic approach based on the experimental measurement of only three points. This is based on the expression:

$$y'(t) = k\, y(t) \tag{1}$$

Where:

k is a positive constant, $y'(t)$ is proportional to the population present at time t.

This differential equation has as a solution $y(t) = Ce^{kt}$, however, in a real situation there are restrictions, such as lack of food, change of pH among others, thus limiting the exponential growth. Thus, when describing a population there is often a maximum capacity (B), beyond which there can be no growth; that is, it is the maximum population $y(t)$ that can be sustained or supported as time t increases.

Under this analysis, it is reasonable to consider that the rate of population growth is proportional to the potential population $B - y(t)$; expressed by the following logistic differential equation:

$$y'(t) = k[B - y(t)]y(t) \tag{2}$$

Or, equivalently,

$$\frac{dy}{dt} = ky(B - y) \tag{3}$$

Intern. Journal of Profess. Bus. Review. | Miami, v. 9 | n. 1 | p. 01-19 | e03654 | 2024.

5

The logistic differential equation is of separable variables, the solution of which is:

$$\frac{1}{B}\ln\left|\frac{y}{B-y}\right| = kt + C \tag{4}$$

Since $y > 0$ and $B > 0$ the absolute value bars can be eliminated; furthermore, taking $y = y_0$ at $t = 0$, the result is:

$$y = \frac{B}{1 + \left(\frac{B}{y_0} - 1\right)e^{-Bkt}} \tag{5}$$

The restricted population growth model, given by expression (5), is known as a logistic model.

The authors showed that the function expressing coliform growth, defined in $[0, \infty[$, is an injective function, because its correspondence is one-to-one and furthermore, by derivation, that the inflection point is $\left(\frac{1}{Bk}\ln\left(\frac{B}{y_0} - 1\right), \frac{B}{2}\right)$, with a maximum capacity B (Figure 1). They also showed that the coliform growth function is continuous in the half-open interval $[0, \infty[$ for $\forall\, t \in Dom\, y(t)$ and that $B = y_{máx} = \lim_{t\to\infty} y$.

Figure 2. Evolution of coliform growth according to the proposed logistic model
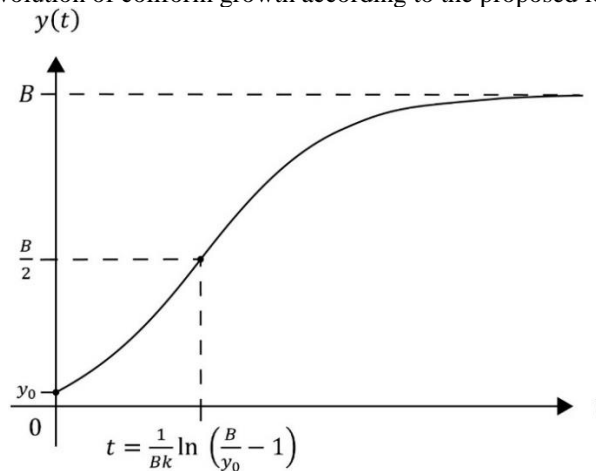
Source: Prepared by the authors (2023).

Methodology of the Model

In order to apply the coliform growth evolution model given by expression (5), experimental measurements of y_0, y_1 and y_2 values at times $t_0 = 0$, $t_1 = 1$ and $t_2 = 2$,

Intern. Journal of Profess. Bus. Review. | Miami, v. 9 | n. 1 | p. 01-19 | e03654 | 2024.

6

respectively, with specified time units, must be considered (Geiss & Ylinen, 2020; Mariani & Tweneboah, 2016). In this case, applying expression (5) to the points $(1, y_1)$ and $(2, y_2)$, it must be satisfied that:

$$y_1 = \frac{B}{1 + \left(\frac{B}{y_0} - 1\right) e^{-Bk}} \tag{6}$$

y,

$$y_2 = \frac{B}{1 + \left(\frac{B}{y_0} - 1\right) e^{-2Bk}} \tag{7}$$

To determine B in terms of the experimental values y_0, y_1 and y_2, clear B from eq. (6):

$$B = \frac{y_0 y_1 (1 - e^{-Bk})}{y_0 - y_1 e^{-Bk}} \tag{8}$$

Proceeding analogously with eq. (7), it is obtained:

$$B = \frac{y_0 y_2 (1 - e^{-2Bk})}{y_0 - y_2 e^{-2Bk}} \tag{9}$$

Dividing eq. (9) by eq. (8), it follows that:

$$e^{-Bk} = \frac{y_0 (y_1 - y_2)}{y_2 (y_0 - y_1)} \tag{10}$$

Substituting eq. (10) into eq. (8), we obtain:

$$B = \frac{y_1 (y_0 y_1 - 2 y_0 y_2 + y_1 y_2)}{y_1^2 - y_0 y_2} \tag{11}$$

The proportionality constant, k, of equation (2) relating the growth rate of coliforms is obtained by clearing B from eq. (10) and replacing it in eq. (11):

Intern. Journal of Profess. Bus. Review. | Miami, v. 9 | n. 1 | p. 01-19 | e03654 | 2024.

7

$$k = \frac{(y_1^2 - y_0 y_2) \ln \frac{y_2(y_0 - y_1)}{y_0(y_1 - y_2)}}{y_1(y_0 y_1 - 2 y_0 y_2 + y_1 y_2)} \tag{12}$$

To obtain the growth function, in terms of the experimentally measured parameters y_0, y_1 and y_2 y_0, it is required to substitute eqs. (11) and (12) in the expression (5), i.e:

$$y = \frac{y_1(y_0 y_1 - 2 y_0 y_2 + y_1 y_2)}{(y_1^2 - y_0 y_2)\left\{1 + \left[\frac{y_1(y_0 y_1 - 2 y_0 y_2 + y_1 y_2)}{y_0(y_1^2 - y_0 y_2)} - 1\right]\left[\frac{y_0(y_1 - y_2)}{y_2(y_0 - y_1)}\right]^t\right\}} \tag{13}$$

The latter expression imposes conditions on the measured values of y_0, y_1 and y_2 such that they give real and positive values of y, B and k.

Computational Structure of the Bacterial Growth Model

The applicability of the model given by eq. (12) to real situations is complemented with the construction of a computer software (unpublished), this facilitates the understanding of the phenomenon, as well as the reduction of time in obtaining results.

The structure of the software created and called Growth Model was made in the integrated development environment (IDE) Visual Studio Community 2017, in the programming language (logic) in Visual C#, with the design language (interface) XAML, for compatible Windows systems (XP, 7 Vista, 8, 8.1, 10), the compatible architecture is 32/64 bits.

The program runs on the Windows Presentation Foundation (WPF) platform, which is a programming model for creating modern business applications on Windows. In addition, it makes use of the LiveCharts library, which enables the visualisation of data in interactive, robust and flexible line charts.

RESULTS AND DISCUSSION

The three values given by eq. (13), were obtained from two samples of wastewater from the Riobamba city sewer discharge into the Chambo river (Figure 2), east of the city.

Figure 2. Location of the sampling point
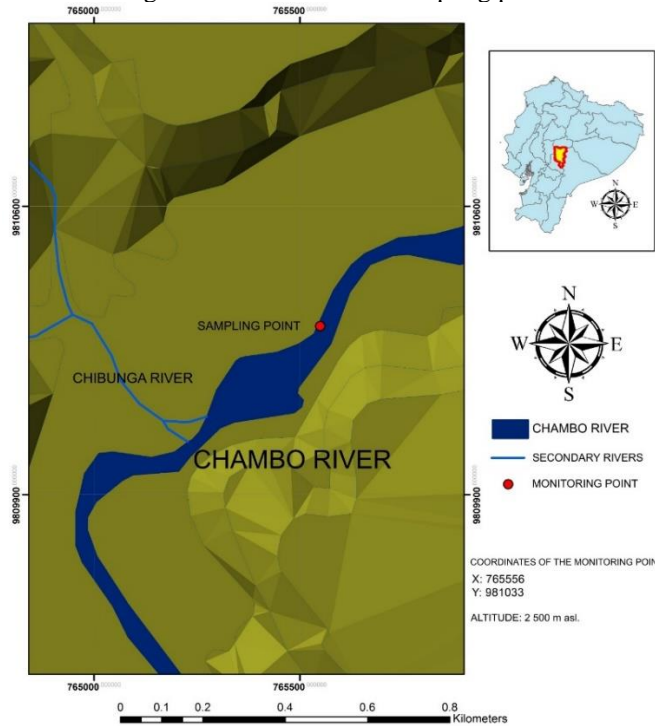
Source: Prepared by the authors (2023).

The characteristics of the pollutant load in mean values of chemical oxygen demand (COD) is 546 mg/L for the two samples, which were analysed according to the standard method 5220-D, the analysis of total coliforms was carried out with the standard method 9221-C, the values obtained for total coliforms of sample 1 are reported in Table 1, noting that it was carried out in three repetitions, measuring the concentration in the laboratory on 3 days of growth.

Table 1. Daily measured values of total coliforms

Sample 1	Date	Total Coliforms (NMP/100 mL)
Repetition 1	16/10/2022	99800
	17/10/2022	116000
	18/10/2022	128000
Repetition 2	16/10/2022	99700
	17/10/2022	115900
	18/10/2022	127960
Repetition 3	16/10/2022	99770
	17/10/2022	115950
	18/10/2022	128050

Source: Prepared by the authors (2023).

Intern. Journal of Profess. Bus. Review. | Miami, v. 9 | n. 1 | p. 01-19 | e03654 | 2024.

9

For sample 2, on the other hand, total coliforms were measured at 3-hour intervals over two days (Table 2), thus providing two types of data on total coliform growth.

Table 2. Two-day interval values for total coliforms

Time	Total Coliform (NMP/100 mL)
13H40	184500
16H40	204250
19H40	217750
13H40	241000
16H40	238000

Source: Prepared by the authors (2023).

By means of expression (11), the maximum theoretical concentration of coliforms that will be reached in an infinite time is obtained; that is to say, the maximum capacity, B. Table 3 shows this value together with the value obtained experimentally and the percentage error between them, for each of the samples analysed.

Table 3. Maximum concentrations of total coliforms

Sample	Repetition	Maximum concentration of total coliforms (NMP/100 mL)		Percentage error between theoretical and experimental concentration
		Theoretical	Experimental	
1	1	149085	148760	0,2%
1	2	149436	148640	0,5%
1	3	149889	147560	1,6%
2	-	239539	238000	0,6%

Source: Prepared by the authors (2023).

With the application of the model given by equation (5) and making use of the computational environment developed for this purpose, coliform values (Table 4) are predicted, from the time the sample is taken until the following nine days, at one-day intervals.

Table 4. Predicting total coliform concentrations with the logistic model

Time (days)	Total coliforms (NMP/100 mL)			
	Sample 1			Sample 2
	Repetition 1	Repetition 2	Repetition 3	
0	99800	99770	99700	184500
1	116000	115950	115900	204250
2	128000	128050	127960	217750
3	136133	136340	136179	226417
4	141320	141685	141449	231760
5	144499	144997	144697	234971
6	146401	146999	146650	236872

Intern. Journal of Profess. Bus. Review. | Miami, v. 9 | n. 1 | p. 01-19 | e03654 | 2024.

10

| Time (days) | Total coliforms (NMP/100 mL) | | | |
| | Sample 1 | | | Sample 2 |
	Repetition 1	Repetition 2	Repetition 3	
7	147523	148192	147808	237987
8	148179	148896	148487	238638
9	148560	149309	148884	239017

Source: Prepared by the authors (2023).

The curves obtained with the model and calculated with the Growth Model software for the 2 samples studied are shown below (Figure 3a to Figure 3d). In all these figures the experimental values are indicated in the upper left tables, which correspond in the figures to the white dots, while the remaining set of blue dots (7) are the values predicted by the model on the number of bacteria as a function of time.

Figure 3. Growth curve for sample 1: a) repetition 1, b) repetition 2 y c) repetition 3; Growth curve for sample 2
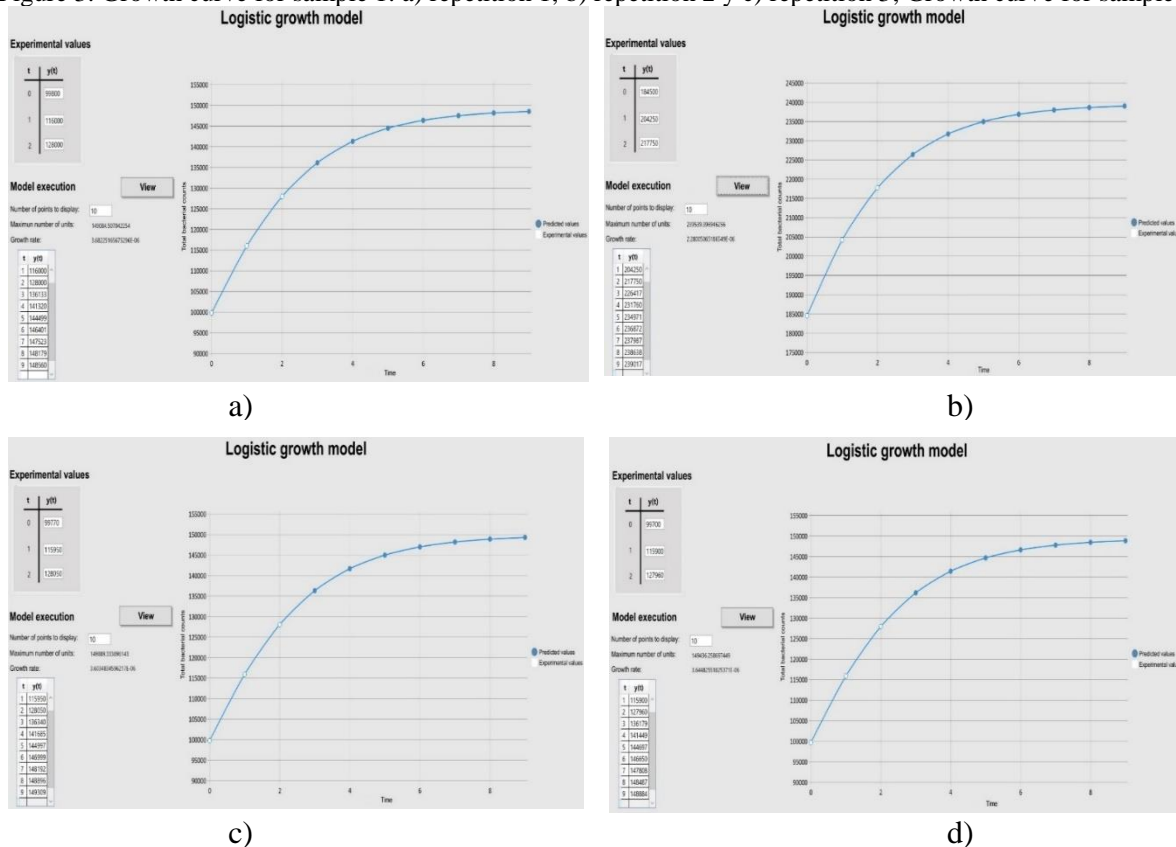
Source: Prepared by the authors (2023).

These figures show the classical behaviour of population growth subject to restrictions; that is, following the logistic model and reaching values close to the horizontal asymptote. This is in agreement with other works by Girdzijauskas & Boguslauskas (2005); Miranda & Lima (Miranda & Lima, 2010); Chen et al., (2022), among others, even though they use other methodologies.

Figure 4 shows the relatively small variation between the 3 replicates of sample 1 according to total coliform growth.

Figura 4. Variation between total coliform growth curves for sample 1 in the three replicates
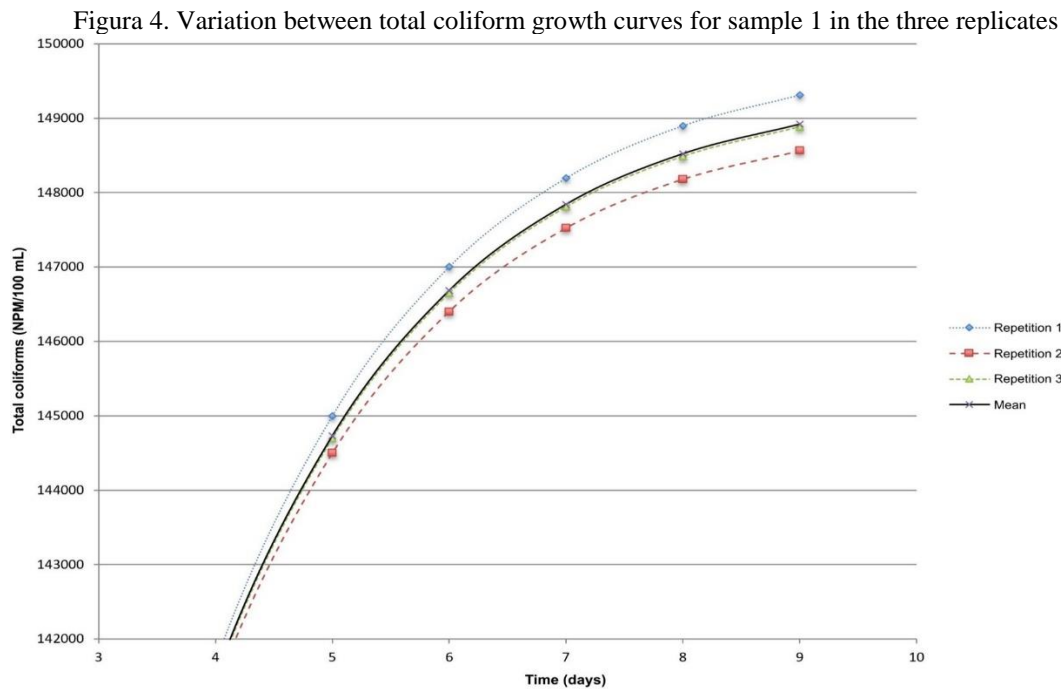
Source: Prepared by the authors (2023).

Discussion

Urban wastewater represents one of the main sources of contamination of interconnected water bodies of many types, such as rivers, lakes, ponds, wetlands and reservoirs (Pinto & Shimakawa, 2022; Sekharan et al., 2022), and its discharge (even treated) to water bodies could increase the levels of these emerging pollutants in the environment, disrupting the ecological balance (Calero-Cáceres et al., 2022; Villa-Achupallas et al., 2018). Although several studies have shown that urban discharges promote the persistence and spread of antibiotic resistance, limited information is available from developing countries (Arcentales-Ríos et al., 2022). Moreover, this impact may be exacerbated in countries where wastewater treatment coverage is still low or technologically weak (Calero-Cáceres et al., 2022).

In the case of Ecuador, there is a lack of adequate wastewater treatment facilities and recent studies have shown a high prevalence of contamination of interconnected water bodies in the country (Arcentales-Ríos et al., 2022; Calero-Cáceres et al., 2022). Such impairments are related to the amount of pollution that has occurred in or near the water body (Sanchez et al., 2020). While the cost of environmental asset and degradation is significant to society in Ecuador, the full cost of environmental externalities has not been taken into account because

Intern. Journal of Profess. Bus. Review. | Miami, v. 9 | n. 1 | p. 01-19 | e03654 | 2024.

12

the value of ecosystem services is not easily measured or accounted for in national accounts (Arcentales-Ríos et al., 2022; Capparelli et al., 2021; González-Zeas et al., 2022). However, there are very few studies that provide information on the economic cost of pollution in this and other environmental media.

The wastewater conditions of the effluent studied vary over time, this is due to the different activities carried out in the city of Riobamba, and even the climatic season in which the samples were taken, this is evidenced by the initial value of total coliforms found in each of the samples: in the first sample an initial mean value of 99757 NMP/100 mL was found and in the second a value of 184500 NMP/100 mL. Reports by Selover et al., (2021) and Nnaji et al., (2019), reported similar results in each of their investigations, which may also explain the consistency of our findings.

The behaviour of the growth of total coliforms varies in the 3 replicates of sample 1, this is due to the experimental error due to laboratory counting, producing an average error of 0.14% between replicates. Thus, the error found guarantees the reliability of the results obtained by the proposed model.

With the values obtained from the laboratory measurements (Tables 1 and 2), the model is able to reproduce the behaviour of coliform growth, thus generating the growth curve and the theoretical maximum value for the samples studied, which coincides with the value found experimentally with a margin of error of 0.8% and 0.6% respectively. Although there are other proposals to reproduce the growth of coliforms, such as Zwietering et al., (1990) and Pinto & Shimakawa (2022), among others; the construction of a logistic model with a deterministic approach based on only three experimental measurements as in the present research is not found in the scientific literature, which has implications in terms of reducing resources and time to obtain the information; in addition to understanding the phenomenon in a different way.

The results shown in this research reflect the current condition in the Rio Chambo area. This information can be used by stakeholders to determine actions that could improve the current conditions. The implementation of possible actions to restore water quality requires a scenario analysis that can give a quantitative prediction of their impact on the restoration of the river. In future research, the analysis and optimisation of different measures to improve biological water quality could be carried out through an integrated ecological model, in which hydromorphological pressure and physico-chemical pollution can be assessed in parallel.

The ecological quality of freshwater bodies is affected by both physicochemical changes and hydromorphological variations caused by natural and anthropogenic stressors (Carrillo et

Intern. Journal of Profess. Bus. Review. | Miami, v. 9 | n. 1 | p. 01-19 | e03654 | 2024.

13

al., 2021; Suszek-Łopatka et al., 2021). To preserve aquatic ecosystems, regions such as the European Union and countries such as the United States have introduced the concept of ecological status in river management into their policies (Pallero et al., 2018; Schütze et al., 2022; Sekharan et al., 2022). This status includes an integrated assessment of biological, hydromorphological and physico-chemical elements of water quality (Choi & Seo, 2018; Thamagasorn & Pharino, 2019).

CONCLUSION

It has been shown that there is consistency between the values obtained from the model and the experimental results when reproducing the growth of total coliforms. In particular, in this study the average experimental value of coliforms in sample 1 was found to be 148320 NMP/100 mL, which coincides with the value predicted by the model of 149470 NMP/100 mL with a margin of error of 0.8%; while in sample 2 their values were respectively 238000 NMP/100 mL and 239539 NMP/100 mL, coinciding with a margin of error of 0.6%.

According to the objective of this research, its contribution is to predict the number of coliforms in a controlled laboratory environment (not in the locality where the sample is taken), which was achieved by starting from only 3 experimental data and applying an analytical method and not a statistical model. Thus, this work contributes to a better understanding of total coliform growth, which is currently a challenge for those studying predictive microbiology, since most models are statistical models that require a large number of samples to be taken for analysis, with the consequent effect on costs and time.

Although the model can reproduce the growth of coliforms up to a maximum growth point, it is necessary to continue with its development in the stationary phase of bacterial growth and then in the decay phase, but by means of an analytical treatment such as the one addressed in this work, in order to better understand the life cycle of this type of bacteria.

REFERENCES

Andrée, D. C., Marie Anne Eurie, F., Niels, D. T., Isabel, G. A., Arne, D., Wout, V. E., Lenin, R. F., Jasmine, D. R., Liesbeth, J., Pieter, S., Luis, D. G., & Peter L.M., G. (2021). From field to plate: Agricultural pesticide presence in the guayas estuary (Ecuador) and commercial mangrove crabs. *Environmental Pollution*, *289*(August). https://doi.org/10.1016/j.envpol.2021.117955

Arcentales-Ríos, R., Carrión-Méndez, A., Cipriani-Ávila, I., Acosta, S., Capparelli, M., Moulatlet, G. M., & Pinos-Vélez, V. (2022). Assessment of metals, emerging contaminants, and physicochemical characteristics in the drinking water and wastewater of Cuenca, Ecuador.

Journal of Trace Elements and Minerals, 100030. https://doi.org/https://doi.org/10.1016/j.jtemin.2022.100030

Bhatia, D., Kumar, R., Singh, R., Chadetrik, R., & Bishnoi, N. R. (2011). Statistical modelling and optimization of substrate composition for bacterial growth and cadmium removal using response surface methodology. *Ecological Engineering*, *37*(12), 2076-2081. https://doi.org/https://doi.org/10.1016/j.ecoleng.2011.08.014

Calero-Cáceres, W., Tadesse, D., Jaramillo, K., Villavicencio, X., Mero, E., Lalaleo, L., Welsh, C., Villacís, J. E., Quentin, E., Parra, H., Ramirez, M. S., Harries, A. D., & Balcázar, J. L. (2022). Characterization of the genetic structure of mcr-1 gene among Escherichia coli isolates recovered from surface waters and sediments from Ecuador. *Science of The Total Environment*, *806*, 150566. https://doi.org/https://doi.org/10.1016/j.scitotenv.2021.150566

Capparelli, M. V., Molinero, J., Moulatlet, G. M., Barrado, M., Prado-Alcívar, S., Cabrera, M., Gimiliani, G., Ñacato, C., Pinos-Velez, V., & Cipriani-Avila, I. (2021). Microplastics in rivers and coastal waters of the province of Esmeraldas, Ecuador. *Marine Pollution Bulletin*, *173*(August). https://doi.org/10.1016/j.marpolbul.2021.113067

Carrillo, K. C., Drouet, J. C., Rodríguez-Romero, A., Tovar-Sánchez, A., Ruiz-Gutiérrez, G., & Viguri Fuente, J. R. (2021). Spatial distribution and level of contamination of potentially toxic elements in sediments and soils of a biological reserve wetland, northern Amazon region of Ecuador. *Journal of Environmental Management*, *289*(November 2020). https://doi.org/10.1016/j.jenvman.2021.112495

Chen, H., Xu, L., Ai, W., Lin, B., Feng, Q., & Cai, K. (2020). Kernel functions embedded in support vector machine learning models for rapid water pollution assessment via near-infrared spectroscopy. *Science of The Total Environment*, *714*, 136765. https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.136765

Chen, L., Mu, T., Li, X., & Dong, J. (2022). Population Prediction of Chinese Prefecture-Level Cities Based on Multiple Models. *Sustainability (Switzerland)*, *14*(8), 1-23. https://doi.org/10.3390/su14084844

Choi, S. Y., & Seo, I. W. (2018). Prediction of fecal coliform using logistic regression and tree-based classification models in the North Han River, South Korea. *Journal of Hydro-environment Research*, *21*, 96-108. https://doi.org/https://doi.org/10.1016/j.jher.2018.09.002

Dzhamtyrova, R., & Kalnishkan, Y. (2020). Universal algorithms for multinomial logistic regression under Kullback–Leibler game. *Neurocomputing*, *397*, 369-380. https://doi.org/https://doi.org/10.1016/j.neucom.2019.06.105

Erbas, A., Allman, T., & Baganz, F. (2014). Bacterial growth modeling for rapid fermentation process development using a parallel mini-bioreactor system. *New Biotechnology*, *31*, S124. https://doi.org/https://doi.org/10.1016/j.nbt.2014.05.1917

Fujikawa, H., Kai, A., & Morozumi, S. (2003). A New Logistic Model for Bacterial Growth. *Food Hygiene and Safety Science (Shokuhin Eiseigaku Zasshi)*, *44*(3), 155-160. https://doi.org/10.3358/shokueishi.44.155

Intern. Journal of Profess. Bus. Review. | Miami, v. 9 | n. 1 | p. 01-19 | e03654 | 2024.

15

Geiss, S., & Ylinen, J. (2020). Weighted bounded mean oscillation applied to backward stochastic differential equations. *Stochastic Processes and their Applications*, *130*(6), 3711-3752. https://doi.org/https://doi.org/10.1016/j.spa.2019.10.007

Girdzijauskas, S., & Boguslauskas, V. (2005). The Possibilities for the Application of the Logistic Model of accumulation. *Engineering Economics*, *41*(1), 7-15.

Gompertz. (1825). On the nature of the function expressive of the law of human mortality, and on a new mode of determining the value of life contingencies. *Francis Baily, Esq. FRS &c. Philosophical transactions of the Royal Society of London*, *115*, 513-583. https://doi.org/https://doi.org/10.1098/RSTL.1825.0026

González-Zeas, D., Rosero-López, D., Muñoz, T., Osorio, R., De Bièvre, B., & Dangles, O. (2022). Making thirsty cities sustainable: A nexus approach for water provisioning in Quito, Ecuador. *Journal of Environmental Management*, *320*(August). https://doi.org/10.1016/j.jenvman.2022.115880

Gruber, J. S., Ercumen, A., & Colford, J. M. (2014). Coliform bacteria as indicators of diarrheal risk in household drinking water: Systematic review and meta-analysis. *PLoS ONE*, *9*(9), e107429. https://doi.org/10.1371/journal.pone.0107429

Habib, M. A., Cocciolo, S., Haque, M. A., Raihan, M. M. A., Bhattacharya, P., & Tompsett, A. (2023). How to clean a tubewell: the effectiveness of three approaches in reducing coliform bacteria. *Science of The Total Environment*, *872*, 161932. https://doi.org/https://doi.org/10.1016/j.scitotenv.2023.161932

Hadi, P. (2023). Improving Firm Sustainability Through Dynamic Capability: The Mediation Role of Ambidexterity. *International Journal of Professional Business Review*, *8*(5), e01511. https://doi.org/10.26668/businessreview/2023.v8i5.1511

He, Z., Xu, X., Hu, Y., Han, J., Wang, X., Xing, Q., Wang, X., & Chen, H. (2023). Distributions, influencing factors and fluxes of dissolved methane in the North Yellow Sea, near the Yalu River estuary, China. *Continental Shelf Research*, *266*, 105081. https://doi.org/https://doi.org/10.1016/j.csr.2023.105081

Herfiantara, B., & Famiola, M. (2023). The Ecosystem of Shared Value Model for the Community Development Program in Saguling Hydroelectric Power Station Area (West Java). *International Journal of Professional Business Review*, *8*(4), 1-21. https://doi.org/10.26668/businessreview/2023.v8i4.1476

Iqbal, I., Tian, G., Bin, X., & Wang, Z. (2022). GPR antennas geometry and its impact over detection of near-surface water contamination through AVO Data analysis at laboratory site. *Journal of Applied Geophysics*, *205*(September 2020), 104758. https://doi.org/10.1016/j.jappgeo.2022.104758

Kim, H. W., Lee, K., Kim, S. H., & Rhee, M. S. (2018). Predictive modeling of bacterial growth in ready-to-use salted napa cabbage (Brassica pekinensis) at different storage temperatures. *Food Microbiology*, *70*, 129-136. https://doi.org/https://doi.org/10.1016/j.fm.2017.09.017

Küpper, T., Apel, C., Bertsch, D., van der Giet, M., van der Giet, S., Graß, M., Cerfontaine, C., Haunolder, M., Hundt, N., Kühn, C., Morrison, A., Museo, S., Timmermann, L., Wernitz, K.,

& Jäger, J. (2022). Analysis of local drinking water for fecal contamination in Solu-Khumbu / Mt. Everest region, Nepal. *International Journal of Hygiene and Environmental Health*, *246*(September). https://doi.org/10.1016/j.ijheh.2022.114043

Łobacz, A., Żulewska, J., & Kowalik, J. (2022). *Chapter 3 - Predictive microbiology and risk analysis* (A. G. da Cruz, C. S. Ranadheera, F. Nazzaro, & A. M. B. T.-D. F. Mortazavian (eds.); pp. 47-68). Woodhead Publishing. https://doi.org/https://doi.org/10.1016/B978-0-12-820478-8.00011-0

Mariani, M. C., & Tweneboah, O. K. (2016). Stochastic differential equations applied to the study of geophysical and financial time series. *Physica A: Statistical Mechanics and its Applications*, *443*, 170-178. https://doi.org/https://doi.org/10.1016/j.physa.2015.09.080

Miranda, L. C. M., & Lima, C. A. S. (2010). On the logistic modeling and forecasting of evolutionary processes: Application to human population dynamics. *Technological Forecasting and Social Change*, *77*(5), 699-711. https://doi.org/https://doi.org/10.1016/j.techfore.2010.01.006

Nnaji, C. C., Nnaji, I. V., & Ekwule, R. O. (2019). Storage-induced deterioration of domestic water quality. *Journal of Water Sanitation and Hygiene for Development*, *9*(2), 329-337. https://doi.org/10.2166/washdev.2019.151

Pallero, C., Barragán, J. M., & Scherer, M. (2018). Management international estuarine systems: The case of the Guadiana river (Spain-Portugal). *Environmental Science & Policy*, *80*, 82-94. https://doi.org/https://doi.org/10.1016/j.envsci.2017.11.005

Pinto, C., & Shimakawa, K. (2022). A compressed logistic equation on bacteria growth: inferring time-dependent growth rate. *Physical Biology*, *19*(6), 66003. https://doi.org/10.1088/1478-3975/ac8c15

Polese, P., Del Torre, M., Spaziani, M., & Stecchini, M. L. (2011). A simplified approach for modelling the bacterial growth/no growth boundary. *Food Microbiology*, *28*(3), 384-391. https://doi.org/https://doi.org/10.1016/j.fm.2010.09.011

Pras, A., & Mamane, H. (2023). Nowcasting of fecal coliform presence using an artificial neural network. *Environmental Pollution*, *326*, 121484. https://doi.org/https://doi.org/10.1016/j.envpol.2023.121484

Rai, P. K., Islam, M., & Gupta, A. (2022). Microfluidic Devices for the Detection of Contamination in Water Samples: A Review. *Sensors & Actuators: A. Physical*, *347*(October 2021), 113926. https://doi.org/10.1016/j.sna.2022.113926

Razanamahandry, L. C., Andrianisa, H. A., Karoui, H., Podgorski, J., & Yacouba, H. (2018). Prediction model for cyanide soil pollution in artisanal gold mining area by using logistic regression. *CATENA*, *162*, 40-50. https://doi.org/https://doi.org/10.1016/j.catena.2017.11.018

Richards, F. J. (1959). A Flexible Growth Function for Empirical Use. *Journal of Experimental Botany*, *10*(2), 290-301. https://doi.org/10.1093/jxb/10.2.290

Intern. Journal of Profess. Bus. Review. | Miami, v. 9 | n. 1 | p. 01-19 | e03654 | 2024.

17

Sanchez, E., Vinueza, R., Izurieta, X., & Rey, N. (2020). Use of muralism to promote awareness about aquatic ecosystems and wise water consumption in northwestern Ecuador. *Ocean and Coastal Management*, *190*(March). https://doi.org/10.1016/j.ocecoaman.2020.105165

Schütze, N., Thiel, A., & Villamayor-Tomas, S. (2022). Coordination across the policy cycle: Uncovering the political economy of river basin management in Spain. *Environmental Science & Policy*, *135*, 182-190. https://doi.org/https://doi.org/10.1016/j.envsci.2022.05.007

Sekharan, S., Samal, D. R., Phuleria, H. C., Chandel, M. K., Gedam, S., Kumar, R., Sethi, V., Supate, A. R., & Karmakar, S. (2022). River pollution monitoring over an industrial catchment in urban ecosystem: Challenges and proposed geospatial framework. *Environmental Challenges*, *7*, 100496. https://doi.org/https://doi.org/10.1016/j.envc.2022.100496

Selover, B., Johnson, J., & Waite-Cusic, J. G. (2021). Population dynamics of coliforms in a commercial Cheddar cheese production facility. *Journal of Dairy Science*, *104*(7), 7480-7488. https://doi.org/10.3168/jds.2020-19808

Sila, O. N. a. (2019). Physico-chemical and bacteriological quality of water sources in rural settings, a case study of Kenya, Africa. *Scientific African*, *2*, e00018. https://doi.org/10.1016/j.sciaf.2018.e00018

Sotomayor, G., Hampel, H., Vázquez, R. F., & Goethals, P. L. M. (2020). Multivariate-statistics based selection of a benthic macroinvertebrate index for assessing water quality in the Paute River basin (Ecuador). *Ecological Indicators*, *111*(July 2019), 106037. https://doi.org/10.1016/j.ecolind.2019.106037

Sreenivas, A., Srinivasa, C., & Supriya, K. (2020). Growth Rates, Growth Models and Future Projections of Sorghum in Telangana State. *International Journal of Current Microbiology and Applied Sciences*, *9*(12), 2514-2524. https://doi.org/10.20546/ijcmas.2020.912.299

Stannard, C. J., Williams, A. P., & Gibbs, P. A. (1985). Temperature/growth relationships for psychrotrophic food-spoilage bacteria. *Food Microbiology*, *2*(2), 115-122. https://doi.org/10.1016/S0740-0020(85)80004-6

Succurro, A, Moejes, F. W., & Ebenhöh, O. (2017). A Diverse Community To Study Communities: Integration of Experiments and Mathematical Models To Study Microbial Consortia. *Journal of Bacteriology*, *199*(15), e00865-16. https://doi.org/10.1128/JB.00865-16

Succurro, Antonella, & Ebenhöh, O. (2018). Review and perspective on mathematical modeling of microbial ecosystems. *Biochemical Society Transactions*, *46*(2), 403-412. https://doi.org/10.1042/BST20170265

Suchetana, B., Rajagopalan, B., & Silverstein, J. (2019). Investigating regime shifts and the factors controlling Total Inorganic Nitrogen concentrations in treated wastewater using non-homogeneous Hidden Markov and multinomial logistic regression models. *Science of The Total Environment*, *646*, 625-633. https://doi.org/https://doi.org/10.1016/j.scitotenv.2018.07.194

Suszek-Łopatka, B., Maliszewska-Kordybach, B., Klimkowicz-Pawlas, A., & Smreczak, B. (2021). The multifactorial assessment of the Zn impact on high and low temperature stress towards wheat seedling growth under diverse moisture conditions (optimal and wet) in three

soils. *Journal of Hazardous Materials*, *416*(5), e126087. https://doi.org/10.1016/j.jhazmat.2021.126087

Thamagasorn, M., & Pharino, C. (2019). An analysis of food waste from a flight catering business for sustainable food waste management: A case study of halal food production process. *Journal of Cleaner Production*, *228*(2019), 845-855. https://doi.org/10.1016/j.jclepro.2019.04.312

Ukaogo, P. O., Ewuzie, U., & Onwuka, C. V. (2020). Environmental pollution: Causes, effects, and the remedies. En *Microorganisms for Sustainable Environment and Health*. INC. https://doi.org/10.1016/B978-0-12-819001-2.00021-8

Vanacker, M., Wezel, A., Arthaud, F., Guérin, M., & Robin, J. (2016). Determination of tipping points for aquatic plants and water quality parameters in fish pond systems: A multi-year approach. *Ecological Indicators*, *64*, 39-48. https://doi.org/10.1016/j.ecolind.2015.12.033

Villa-Achupallas, M., Rosado, D., Aguilar, S., & Galindo-Riaño, M. D. (2018). Water quality in the tropical Andes hotspot: The Yacuambi river (southeastern Ecuador). *Science of The Total Environment*, *633*, 50-58. https://doi.org/https://doi.org/10.1016/j.scitotenv.2018.03.165

Zwietering, M. H., Jongenburger, I., Rombouts, F. M., & Van't Riet, K. (1990). Modeling of the bacterial growth curve. *Applied and Environmental Microbiology*, *56*(6), 1875-1881. https://doi.org/10.1128/aem.56.6.1875-1881.1990