



RESEARCH NOTE

Modelling risk using Bayes theorem of infection by antibiotic-resistant *Escherichia coli* in rural and urban populations of Ecuador [version 1; peer review: 2 approved, 1 approved with reservations]

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Abstract

Strains of antibiotic-resistant bacteria have become more and more prevalent. This has attracted the attention of health agencies worldwide, leading to an urgent search for mechanisms to put a stop to this phenomenon. This study focuses on estimating the probability of a person in Ecuador (at potential risk) contracting an infection due to ampicillin-resistant *Escherichia coli* through the consumption of contaminated water, for which a residence area of people was considered in urban or rural areas. The analysis was carried out using the Bayes Theorem and the results show that in the rural population the probability of contracting an infection of this kind is 8.41% whilst in the urban area the probability is 3.57%. These results show an urgent need to provide safe water sources to the population, as well as to instigate an environmental legislation reform that allows for controlling the release of emerging pollutants, including antibiotics.

Keywords

Antibiotic resistance, Emerging pollutants, Risk assessment

Open Peer Review

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	1	2	3
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26 Mar 2018			

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Any reports and responses or comments on the article can be found at the end of the article.

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Author roles: **Ramirez Cando LJ:** Conceptualization, Data Curation, Investigation, Methodology, Supervision, Validation, Writing – Original Draft Preparation, Writing – Review & Editing; **Mátyás B:** Supervision, Writing – Original Draft Preparation, Writing – Review & Editing; **Lozano-Haro ZJ:** Formal Analysis, Investigation, Methodology, Project Administration, Writing – Original Draft Preparation

Competing interests: No competing interests were disclosed.

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Introduction

For years, humankind has sought to mitigate the impacts produced by human development. Perhaps one of the most serious and unregulated problems in legislation is that of emerging pollutants (EP). According to Fernández *et al.* (2016)¹ these are common-use chemical compounds of natural or synthetic origin, which, despite not being considered significant in terms of distribution and/or concentration, present a risk to the environment and human health. Within EPs, antibiotics make up a group that is becoming increasingly important and their presence in the environment has become a global public health problem. Concern surrounding the presence of antibiotics in bodies of water and the subsequent increase in bacterial resistance has led the WHO to publish a list of bacteria that have developed capacities for inhibiting widely-used antibiotics. Bacterial resistance according to Rodríguez, A. (2016)² arises from the excessive and irrational use of antibiotics to treat infections that affect human beings' bodies. This is due to an independent adaptive selection of the bacteria and the family of a specific strain as in the case of *Staphylococcus aureus* and its ability to inhibit conventional penicillin. This is not an isolated event; on the contrary, Cabrera, C. *et al.* (2007)³ maintain that by mutations in the chromosome of certain bacteria or by genetic exchange, bacteria can develop high innate resistance to antibiotics with several mechanisms between species of the same family or between different families. This study will explore the relationship that exists between bacterial resistance to antibiotics as a problem of emerging pollutants and public health for the inhabitants of Ecuador, taking area of residence as the reference.

Methods

In order to estimate the probability of an Ecuadorian contracting an antibiotic-resistant bacterial infection, one must consider the area where the person lives, the presence or absence of *Escherichia coli* in the main sources of water for human consumption in the country, and the antibiotic to be analysed (in this case ampicillin). The analysis was carried out considering the Bayes Theorem which, according to Marrero, D. (2014)⁴, is expressed as the conditional probability of a random event 'A' given another event 'B'. Below is its formula, which takes into account that several events of A can be exclusive:

$$P(A_i | B) = \frac{P(B | A_i)P(A_i)}{\sum_{i=1}^k P(B | A_i)P(A_i)}$$

Where: $P(A_i)$ are the *a priori* probabilities.

$P(B | A_i)$ are the probabilities of B in hypothesis A_i .

$P(A_i | B)$ are the *a posteriori* probabilities.

$\sum_{i=1}^k P(B | A_i)P(A_i)$ is the sum of the probabilities of B in the hypothesis A_i times the *a priori* probabilities.

Our analysis focuses on the occurrence of three events:

- the probability of consuming contaminated water, depending on the area where a person lives.
- the probability that a person who consumes contaminated water will contract an infection due to *Escherichia coli*.
- the probability that the contracted infection is resistant to antibiotics, using ampicillin as a reference.

Results

Determination of the probability that an Ecuadorian will consume contaminated water according to the area where the person lives

In order to carry out this estimate, data published by the INEN according to Ecuadorians' areas of residence has been taken as a reference. The data are shown in Table 1:

Table 1. Urban and rural population in Ecuador, 2010. //Source: INEC, Population census (2010)⁵.

Area	Population	%
Urban	9,090,786	63%
Rural	5,392,713	37%
Total	14,483,499	100%

In the same way, the INEN provides information regarding water quality (shown in Table 2):

Table 2. Water quality according to area of residence. Source: INEC Survey (December, 2016)⁶.

Area	% of uncontaminated water consumption	% of contaminated water consumption
Urban	84.6	15.4
Rural	68.2	31.8
Total	100	100

Thereafter, we applied the aforementioned Bayes Theorem to find out the probability that people living in urban or rural areas who consume drinking water may be contaminated with *Escherichia coli*. For this case:

$P(A_i | B)$ is $P(\text{urban} | \text{contaminated water})$

$P(A_i)$ is $P(\text{urban}) \& P(\text{rural})$

$P(B | A_i)$ is $P(\text{contaminated water} | \text{urban}) \&$

$P(\text{contaminated water} | \text{rural})$

$$\frac{P(\text{urban} | \text{contaminated water}) = \frac{P(\text{contaminated water} | \text{urban})}{\sum_{i=1}^k P(\text{contaminated water} | \text{urban, rural})P(\text{urban, rural})}$$

$$P(\text{urban} | \text{contaminated water}) = 45.19\%$$

By carrying out the same analysis for the rural population, one obtains a 54.81% probability that a person living in the rural area may consume contaminated water (Table 3).

Determination of the probability that an Ecuadorian who consumes contaminated water will contract an infection due to *Escherichia coli*

Once the probability of a person drinking contaminated water is known, it is necessary to find out the probability of contracting an infection due to *Escherichia coli* by consuming contaminated water. According to Vila, J. *et al.* (2016)⁷, in a study of 33 people living in South America in urban and rural areas, there is a 9.1% and 12.2% respectively that they house the aforementioned bacteria.

Table 3. Summary of the probability calculation for the different events

	Distribution of people living in urban or rural areas	Probability of consuming contaminated water	Probability of contracting an <i>E. coli</i> infection	Probability of contracting an infection with a resistant strain	Probability of contracting an ampicillin-resistant infection due to contaminated water consumption
People living in urban areas	63 %	45.19 %	38.08 %	32.97 %	3.57%
People living in rural areas	37 %	54.81 %	61.92 %	67.03 %	8.41%

Determination of the probability that an Ecuadorian who consumes contaminated water will contract an infection caused by antibiotic-resistant *Escherichia coli*

Once the probability of contracting an *E. coli* infection due to contaminated water consumption is identified, it is necessary to find out how many of these infections are resistant to antibiotics, which in our case was ampicillin. Bianchi, V. *et al.*, (2014)⁸, in a study conducted in the San Juan River in Argentina, showed that the average ampicillin-resistant UFC percentage in urban areas was 73.39% and for rural areas 92.85%. Using the Bayes Theorem for each of the cases described above, we obtained the following results:

Conclusions

This study shows that both urban and rural populations are exposed to an antibiotic-resistant infection. However, Ecuador's rural population is more exposed because the water sources they use are not safe. This draws attention to the necessity of providing safe, clean drinking water to the entire population. Even so, the high standards of water quality that many Ecuadorian cities have does not completely eliminate the risk of contracting antibiotic-resistant infections, thus demonstrating that an urgent legislation reform is

required in order to control the release of these types of pollutants into bodies of water.

Data availability

Population and water quality data was obtained from the Instituto Nacional de Estadística y Censos (INEC), Population census (2010): <http://www.ecuadorencifras.gob.ec/base-de-datos-censo-de-poblacion-y-vivienda/> and INEC, Survey (2016): http://www.ecuadorencifras.gob.ec/documentos/web-inec/EMPLEO/2017/Indicadores%20ODS%20Agua,%20Saneamiento%20e%20Higiene/Presentacion_Agua_2017_05.pdf

Competing interests

No competing interests were disclosed.

Grant information

The author(s) declared that no grants were involved in supporting this work.

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Open Peer Review

Current Referee Status:



Version 1

Referee Report 08 May 2019

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Imre Vágó 

Institute of Agricultural Chemistry and Soil Science, Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, Debrecen, Hungary

I read with great interest Ramirez and colleagues' study in which they present an estimation about the probability of contracting infection due to ampicillin-resistant *E. coli* though the consumption of contaminated water in the urban and rural areas of Ecuador.

This publication is a good example for how to obtain valuable and useful knowledge through consistent data analysing and data evaluation. The goal of the study is well described. The manuscript is clear; the used methods in this paper are adequate. However, I would like to share my observations in order to aid readers' understanding.

- Despite the authors analysing separately the urban and rural populations of Ecuador, the basis of the differentiation is not defined.
- In this paper, the data of urban and rural populations in Ecuador is outdated; it referred to 2010 data (Table 1). I mean, it would be better to use the latest published dataset from 2018, source: <https://tradingeconomics.com/ecuador/rural-population-percent-of-total-population-wb-data.html>. It states that the total population is 16,624,858 and also the ratio of urban population (64.3%) increased, compared to 2010.
- The ratio of population consuming *Escherichia coli*-infected water (Table 2) is surprisingly high, especially for the rural population, compared to Europe. Does it really cover reality? Using ampicillin resistance values measured in the Bianchi *et al.* (2014) study in the water of San Juan River in Argentina, is critical. The distance is about 3600 km, the climate conditions are significantly different. Sorry, I am not aware of the ampicillin application frequency in South America, perhaps this is the reason for my doubts about this data.
- Last but not least: there are two typos in the paper. One of them is the missing closing bracket ")" before the equal sign '=' in the Marrero's equation. The other error is in Table 2; instead of last row (Total, 100, 100) it would be better to create another column, with the identical name and values.

In conclusion, the results of the research work are proving that the Bayes Theorem is suitable for the evaluation of elaborated data sets. The publication meets all of the scientific requirements; the results have practical relevance and they can be used by the decision makers also. That is why I suggest the presented paper for indexing.

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Partly

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Plant nutrition

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Referee Report 08 May 2018

<https://doi.org/10.5256/f1000research.15619.r32439>



Andrés Ricardo Izquierdo Romero 

Centro de Nanociencias y Nanotecnología; Departamento de Ciencias de la Vida; Grupo de Investigación en Microbiología y Ambiente GIMA, Universidad de las Fuerzas Armadas ESPE, Sangolquí, Ecuador

The manuscript is clear, however in the manuscript is cited Fernández et al. (2016), and it is not found in the bibliography. I recommend placing more citations of other investigations where Bayes Theorem is used, for this type of investigation.

The statistical analysis if applicable, however I recommend placing the calculations to obtain the values that were obtained and discussed, such as:

- Probability of contracting an *E. coli* infection: 38.08% (people living in urban areas), 61.92% (people living in rural areas)
- Probability of contracting an infection with a resistant strain: 32.97% (people living in urban areas), 67.03% (people living in rural areas)
- Probability of contracting an infection resistant to ampicillin due to the consumption of contaminated water: 3.57% (people living in urban areas), 8.41% (people living in rural areas)

I suggest that it is necessary to show the data for water pollution in rural and urban areas of Ecuador, as well as the parameters for water quality according to the area of residence, such as water contamination with ampicillin-resistant *E. coli*, for estimate the probability of a person in Ecuador contracting an

ampicillin-resistant *Escherichia coli* infection through the consumption of contaminated water, as the manuscript suggests.

The data of Vila, J. et al. (2016) can be used statistically, is a small study of 33 people living in South America in urban and rural areas, compared to the urban and rural population in Ecuador, 2010, which is 14,483,499 people, for the determination of the probability that it is Ecuadorian to consume contaminated water. an infection by *Escherichia coli*. There are data on *E. coli* infections in contaminated water in Ecuador, to strengthen the results obtained.

To determine the probability that an Ecuadorian will consume contaminated water to contract an infection caused by antibiotic-resistant *Escherichia coli*, used data from Bianchi et al. (2014) of the San Juan River in Argentina, showing that the average percentage of CFU resistant to ampicillin in urban areas was 73.39% and for rural areas 92.85%. These data are comparable with water sources in Ecuador, such as rivers, environmental conditions, etc., to be able to use them. Similarly, it is suggested to know if there are data of *E. coli* infections resistant to antibiotics in contaminated water in Ecuador.

In conclusion, the objective of the work is interesting, however, he suggested that to investigate more real data of Ecuador, to strengthen the obtained results.

Is the work clearly and accurately presented and does it cite the current literature?

Partly

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Partly

Are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 11 Dec 2018

Bence Mátyás, Universidad Politécnica Salesiana, Ecuador

Dear Dr. Andrés Ricardo Izquierdo Romero, thank you for your report.

"The manuscript is clear, however in the manuscript is cited Fernández et al. (2016), and it is not found in the bibliography. I recommend placing more citations of other investigations where Bayes Theorem is used, for this type of investigation."

authors' reply:

We will ask for a minor correction in the article regarding the missing citation. Considering this piece is a research note, we do not think that expanding the article with more citations is necessary.

"I suggest that it is necessary to show the data for water pollution in rural and urban areas of Ecuador, as well as the parameters for water quality according to the area of residence, such as water contamination with ampicillin-resistant E. coli, for estimate the probability of a person in Ecuador contracting an ampicillin-resistant Escherichia coli infection through the consumption of contaminated water, as the manuscript suggests."

authors' reply:

This information is presented in external links only in order to keep the research note brief.

"The data of Vila, J. et al. (2016) can be used statistically, is a small study of 33 people living in South America in urban and rural areas, compared to the urban and rural population in Ecuador, 2010, which is 14,483,499 people, for the determination of the probability that it is Ecuadorian to consume contaminated water. an infection by Escherichia coli. There are data on E. coli infections in contaminated water in Ecuador, to strengthen the results obtained."

authors' reply:

The Bayes theorem allows to add more specific information later in a new analysis.

"To determine the probability that an Ecuadorian will consume contaminated water to contract an infection caused by antibiotic-resistant Escherichia coli, used data from Bianchi et al. (2014) of the San Juan River in Argentina, showing that the average percentage of CFU resistant to ampicillin in urban areas was 73.39% and for rural areas 92.85%. These data are comparable with water sources in Ecuador, such as rivers, environmental conditions, etc., to be able to use them. Similarly, it is suggested to know if there are data of E. coli infections resistant to antibiotics in contaminated water in Ecuador... In conclusion, the objective of the work is interesting, however, he suggested that to investigate more real data of Ecuador, to strengthen the obtained results."

authors' reply:

The Bayes theorem allows to add the specific information later in a new analysis, making analysis deeper, however, this research note tends to offer the first step for a further analysis regarding Bayesian statistics.

Competing Interests: No competing interests were disclosed.

Referee Report 28 March 2018

<https://doi.org/10.5256/f1000research.15619.r32440>



Ramirez Robles Jorge Yandry 

Departamento de Química y Ciencias Exactas, Universidad Técnica Particular de Loja, Loja, Ecuador

The methods in this paper are adequate, however, in probability theory, according to Bayes' theorem that describes the probability of an event, based on prior knowledge of conditions that might be related to the event. So, in case of this paper I think it is necessary to show data about pollution water made in different areas of Ecuador, for two reason: the first one is to make known the difference between rural and urban area, and the second one, if "*this study focused on estimating the probability of a person in Ecuador contracting an infection due to ampicillin-resistant Escherichia coli through the consumption of contaminated water*", it's necessary to know if the source of water in Ecuador are contaminated with ampicillin-resistant *E. coli*. So, if the water in Ecuador is contaminated with ampicillin-resistant *E. coli*, is highly probably that the people of Ecuador contracting an infection, then using Bayes' theorem, a water quality of water (contaminated with *E. coli*) can be used to more accurately assess the probability that the contracting an infection, compared to the assessment of the probability of people contracting infection made without knowledge of data of quality of water.

In conclusion the paper is correct because the aim is shows that both urban and rural populations are exposed to an antibiotic-resistant infection, and in Ecuador there aren't researched in this area. For this reason I think the worked can be published.

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Partly

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 11 Dec 2018

Bence Mátyás, Universidad Politécnica Salesiana, Ecuador

We are grateful for Dr. Ramirez Robles Jorge Yandry's report,

We just wish to add that considering Bayes theorem capacity to aggregate new information, starting with non-known data analysis is an effective way.

Competing Interests: We declare no compete of interest.

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