

# Modeling the antimicrobial resistance of enterobacteria responsible for Urinary Tract Infections in Benin: another way to Control or survey Antimicrobial Resistance

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## Research article

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# Abstract

**Background:** Infectious diseases are serious public health issue both in developing countries and industrialized countries. In developing countries, they are the main cause of high mortality rates. In the second group, existing resistance to antibiotics is developing growing at an alarming rate. The purpose of this study was to produce data of national interest to implement sustainable control of antimicrobial resistance as well as it spreads.

**Methods:** One hundred ninety (190) urine samples were collected in several hospitals in Benin from patients suspected of having a urinary tract infection. After getting the inform consent from patients, samples collections were performed under aseptic conditions and were further subjected to bacteriological tests in the laboratory. The resistance profile of the bacterial strains identified was then established. The search for betalactamase production was performed by the synergy test between amoxicillin + clavulanic acid and cephalosporins. Mathematical modeling of the resistance of the strains identified by 2024 was finally carried out using compartmental deterministic models.

**Results:** Two hundred thirty (230) strains were identified from urine samples. Male individuals were the most affected by urinary tract infections. Individuals in the 21-30 age groups were predominant. *Escherichia coli* was the most isolated bacterial species (32.43%) in this study followed by *Klebsiella pneumoniae* (26.85%) and *Enterobacter cloaceae* (25.92%). The susceptibility testing of isolates bacteria to antibiotics showed a strong resistance of strains to amoxicillin (91.82%). The lowest resistance obtained was observed with imipenem (2%). The betalactamase was produced by 24.03% of the strains identified. *Escherichia coli* (32.43%) was indeed the most productive of betalactamase followed by *Klebsiella pneumoniae* (31.03%). Mathematical modeling revealed a rampant rise in the resistance of bacteria to the antibiotics tested.

**Conclusions:** These results provide important data for public health. They deserve constructive advocacy so that more specific actions are taken in relation to antimicrobial resistance.

## Introduction

Infectious diseases are a serious public health issue both in developing countries where they are the main cause of high mortality rates, and in industrialized countries where resistance to existing antibiotics is growing in an alarming rate [1]. In developing countries, infectious diseases are a public health problem because of their frequency and severity. Infectious diseases are responsible for more than 17 million deaths per year in the world with more than half cases coming from Africa alone [2]. Infection of the urinary tract is one of the most common infectious diseases in the hospital and even in the community. This disease one of the most common bacterial infections in pediatrics and a major public health problem. Indeed, urinary tract infection is a serious pathology with a potential risk of progression to other diseases [3]. In fact, this infection is an infection that covers various clinical realities such as uncomplicated acute cystitis, asymptomatic bacteriuria; it can lead to worse conditions including pyelonephritis, prostatitis, urethritis or infection complicating uropathy [4]. The urinary tract infection is extremely frequent among elderly and the symptoms are polymorphous such as asthenia, anorexia, recent incontinence or urgency without urgency [4]. With an incidence of 150–250 million people worldwide [5], urinary tract infections are more prevalent in women. Compared to male sex, urinary tract infection is more prevalent in women.

The annual incidence of these infections is estimated in the United States at 11 million cases and in France at 4 to 6 million cases. In Morocco, and as it is the case in several African countries, urinary tract infections remain frequent and rank first in hospitals [6]. According to several reports, Enterobacteriaceae are the most isolated bacteria of urinary infections headed by *Escherichia coli* [5].

Urinary tract infections are one of the main reasons for consultation, microbiological investigations and intensive use of antibiotics worldwide [7] and particularly in Africa. The poorly controlled use of antibiotics has led to phenomena of bacterial resistance. Bacterial resistance to antimicrobial agents is a problem of increasing importance in medical practice. Dissemination of resistant bacteria is responsible for a considerable increase in mortality, morbidity and cost of treatment [8]. The resistance of Enterobacteriaceae to third-generation cephalosporins (C3G) is strongly enhanced by the acquisition of the genes encoding extended-spectrum beta-lactamases (ESBL). These enzymes (TEM, SHV, CTX-M and derivatives) confer on enterobacteria resistance to all beta-lactams [9].

Enterobacteriaceae are the most targeted by their production betalactamases and have other mechanisms of resistance to many antibiotics as by the production of carbapenemase also.

In Africa and particularly in Benin, urinary tract infections remain endemic and represent the highest reason for consultation among bacterial infections. However, the etiology of the bacteria involved is not known at the national level. In addition, the majority of patients do not have access to medical laboratories and the management of infectious syndromes is still probabilistic. This practice has increased multidrug-resistant bacteria in the community and more in hospitals. All this complicates the management of these urinary tract infections. No studies on bacterial infections and associated resistance have addressed the incidence of multidrug resistance of enterobacteria by production of betalactamase and carbapenemase in urinary tract infections in Benin. Moreover, the control of enterobacterial infections and the need to have an estimate of resistance become paramount [8]. Modeling biological phenomena has several interests. Indeed, it can help describe and better understand certain phenomena. His representational techniques also make it possible to summarize and organize knowledge. The modeling then makes it possible, from collected data, to estimate key parameters, hidden or poorly known or even unknown [8]. Thus, it is therefore an additional tool for decision support in the fight against multidrug resistance. The purpose of this article is to produce data of national interest to more effectively fight against antimicrobial resistance.

## Material And Methods

## 2-1- Material

A cross-sectional prospective and analytical study included all patients suffering from urinary tract infections was done. The study included patients from the following area hospitals and Departmental Hospital Centers of Benin (Table I). These centers were chosen because of their location in the country and also based on the affluence.

The present study was conducted on 190 urine samples collected in Beninese hospitals. These samples were taken from patients who came to the laboratory for the diagnosis of urinary tract infections from May to September 2019. Prior to admission to this study, a written consent was obtained from patients. The consent forms are available from the corresponding author upon request. Total confidentiality was assured to the patients who participated to this study.

## 2-2- Methods

### 2-2-1- Collection of urines and bacteriological examination

Urines were collected throughout Benin. For each patient who came to the identified hospitals for a cytobacteriological examination of urines, a sterile pot was given. Once the samples were aseptically taken, the samples were sent to the Research Unit in Applied Microbiology and Pharmacology of natural substances for diagnosis. Prior to the collection, a survey form was made available to record all possible information about the patient. These informations were related to socio-cultural characteristics. In the laboratory, cytobacteriological examination of urine was performed on each sample according to the procedures described by the authors [10, 11].

### 2-2-2- Antibiogram

Antibiotic susceptibility was determined by the Mueller Hinton agar diffusion method [30]. The resistant enterobacteria by production of betalactamase were screened by the double synergy test as described by [8]. The production of ESBL sought by the double synergy test is in the form of a champagne cork on the agar as shown in the figure S1.

The table II shows the different antibiotics used as well as the corresponding charges.

### 2-2-3- Mathematical modeling of the resistance of isolated bacteria

Following the determination of the antibiotic resistance profile, a mathematical modelisation was performed in six years. The models used were deterministic compartmental models. The purpose of this modeling was to have an estimation of the resistance by 2024 based on our study population. For the resistance profiles not having intermediate resistance, the following model was used:

For resistance profiles with intermediate resistance, the following model was used:

[Due to technical limitations, this equation is only available as a download in the supplemental files section.]

### 2.2.4. Statistical analyzes

The data collected were coded and saved in a Microsoft Excel 2019 database. The graphs were made using the GraphPad Prism 8 software. The proportions were compared using Chi square test.

## Results And Discussion

### 3.1 Results

Figure 1 shows the percentage of samples received per center. Bethesda and Menontin hospitals were the health facilities that receive more patients for cytobacteriological examination of the urine. The study revealed that male patients were mostly affected by the urinary tract infections in Benin (Figure 2a) with a positive proportion of 80% (115 positive samples upon 142) against 87.5 % (35 positive samples upon 48).

The Figure 2b shows the distribution of individuals according to age's group. This figure shows that individuals in the age group between 20 and 30 years were the most represented.

Similarly, the distribution of the study population by age group and sex has shown that women are the most represented in the age group between 20 and 30 years of age (Figure 2c). Cytobacteriological examination of the urine was performed on the different samples collected during the study. Macroscopic examination shows that the urine samples have several aspects with variable turbidity (Figure 3). The table III shows the microscopic examination of the different elements represented in the samples collected.

Figure 4a shows the frequency of the different bacterial species identified after the culture bacteria. It shows that *Escherichia coli* (32.43%) was the most isolated, respectively followed by *Klebsiella pneumoniae* (26.85%) and *Enterobacter cloacae* (25.92%).

The sensitivity of the different bacterial isolates to certain antibiotics was tested. The results obtained are shown in Figure 4b. Table IV shows the resistance profile of these enterobacteria to each antibiotic.

Table V shows the prevalence of the enterobacteria producing betalactamase and among all isolated strains. *Escherichia coli* (24/74) is the bacteria to most produce the betalactamase with *Klebsiella pneumonia* (18/58)

## MODELISTATION OF THE RESISTANCE

The resistance of the different strains has been modeled to have an estimate of their resistance by 2024. For all strains, high levels of resistance will be observed for all antibiotics and only imipenem will show a low level of resistance. However, in *Morganella morganii* strains, even in the presence of imipenem, total resistance will be observed (Figure 5).

Modeling *Klebsiella pneumoniae* strains showed total resistance to some antibiotics by 2024, namely Amoxicillin, Ceftriaxone and Ciprofloxacin. Apart from Imipenem, in which in 2024 a rate of 34.80% will be observed, all the other antibiotics tested will also show high levels of resistance (Figure 5a).

For strains of *Citrobacter diversus*, a 100% resistance rate will be observed for amoxicillin and ciprofloxacin. Imipenem and Aztreonam are the two antibiotics in which relatively low levels of resistance will be observed (Figure 5b).

Strains of *Enterobacter aerogenes* will show high resistance to most antibiotics tested. Only carbapenems will show moderately low resistance rates (Figure 5c).

In 2019, high levels of resistance are already observed against all antibiotics tested in strains of *Morganella morganii* and in 2024, resistance will be total against all antibiotics (Figure 5d).

In *Klebsiella oxytoca*, the resistance rate against all the antibiotics tested will be 100% except for Imipenem which is 22% (Figure 5e).

Strains of *Escherichia coli* will show high levels of resistance to Horizon 2024. However, in the face of Imipenem, the resistance rate remains low (Figure 5f).

In 2024, the strains of *Enterobacter cloacae*, will also show a high level of resistance against all the antibiotics tested except face Imipenem which will be 22.04% while it was zero in 2019 (Figure 5g).

## DISCUSSION

In less advanced countries such as Benin, bacterial infections including urinary tract infection remain a major public health issue given their frequency and antimicrobial resistance [12]. Several bacterial species are involved as far as urinary tract infections are concerned. The general objective of this study was to determine the main enterobacteriaceae responsible for urinary tract infections in Benin and to evaluate the level of resistance of these uropathogenic bacteria to betalactamines and carbapenems by production of betalactamase and carbapenemase. This study was carried out throughout the territory allowing first of all to collect the samples of the patients, and then send to the laboratory of medical bacteriology of the reference centers for cytobacteriological examination of the urine. These are district hospitals and Departmental Hospital Centers in Benin. These centers were chosen according to the geographical location in the country, the affluence in terms of microbiological diagnosis and especially based on the presence or absence of a laboratory of medical bacteriology. Thus, a total of 190 urine samples were collected. On average, fifteen [13] urine samples are received per week in the surveyed hospitals. This influx would be justified by the real public health issue which is the urinary tract infections in developing countries like Benin [14]. Several researchers have reported in various studies that urinary tract infections are the most common infectious bacterial diseases in hospital and community settings [15, 16]. This state of affairs shows that urinary tract infections are endemic to Benin.

The ratio of male to female has shown those males are the most affected by urinary tract infections. This result opposite the work of several authors. The latter have shown that it depends on the woman's urinary system. Pregnant women are the most affected as pregnancy is a physiological state that weakens the woman's immune system [17, 18, 19]. In addition, among the population studied, individuals in the age group between 21 and 30 years are the most affected by urinary tract infections and among these, women are the most represented. The female predominance is related to the anatomical configuration: shortness of the urethra, proximity of the genital and anal openings, insufficient hygiene practices, sexual intercourse and pregnancy. [20] reported a similar result in his study on enterobacterial phenotypes responsible for community and nosocomial infections. However, urinary cytology showed epithelial cells, urinary crystals, kidney cells and leukocytes which are the most numerous. These results corroborate those of [21] in their study carried out on the resistance phenotypes of *Escherichia coli* strains responsible for urinary infection in the laboratory of the University Medical Center of Befelatanana in Antananarivo.

In the present, more than 230 Enterobacteriaceae have been isolated from the urine samples. *Escherichia coli* (32.42%) is the most isolated bacterial species followed respectively by *Klebsiella pneumoniae* (26.85%) and *Enterobacter cloacae* (25.92%). This result corroborates several studies conducted by researchers from several countries who have been working on enterobacteria responsible for urinary tract infections. [22, 23, 24, 25, 26]. [27] also obtained similar result. In addition to the commonly encountered species, other bacteria have been isolated. These include *Klebsiella oxytoca*

(6.94%), *Enterobacter aerogenes* (6.02%), *Morganella morganii* (0.92%) and *Citrobacter diversus* (0.92%). The involvement of these bacteria in the case of urinary infection has been demonstrated by other studies [28]. Indeed, most of these authors have shown that these bacteria are also responsible for urinary tract infections but with a very low proportion compared to frequently isolated species.

The study of the sensitivity of isolated strains to enterobacteria shows that they are highly resistant to penicillins including Amoxicillin + clavulanic acid and amoxicillin. This result is similar to that of [29] in his study on the evolution of the resistance of enterobacteria responsible for human infections at the Douala hospital. The different bacterial species isolated showed varying levels of resistance to the different antibiotics used. In the family of betalactamines, penicillins including amoxicillin (50.56%) and amoxicillin / clavulanic acid (91.82%) are the most resistant. Cephalosporins such as cefotaxime (36.24%) and ceftriazone (45.58%) exhibited high resistance as did aztreonam (35.81%). Imipenem (2.00%) showed very low resistance compared to ertapenem (36.07%) in the carbapenem class. In the aminoglycoside family, gentamicin showed a resistance of 33.74%, lower than the resistance level of ciprofloxacin (52.05%) in the quinolone family. The high level of resistance observed in the penicillin class has been demonstrated by other researchers [27, 18, 30]. The latter explained that this resistance is acquired and would be the consequence of the selection pressure linked to the excessive consumption of these antibiotics in the developing countries. This similar result confirms that aminopenicillins are no longer recommended for treating urinary tract infections. The high resistance level of cephalosporins is approximate to the results of [4] but different from those of [15]. The latter found resistance a little lower than ours. This result could be justified by the fact that cephalosporins are the most used antibiotics [11]. Also in the context of our study, the samples were collected in Benin reference centers so patients often come from other health facilities where probabilistic treatments based on the use of these molecules have sometimes already been initiated. Self-medication and lack of infection management guideline can also contribute to increased levels of resistance to these antibiotics in our context. Imipenem had good activity on enterobacterial strains. This trend has also been found in Spain [25]. The evolution of the resistance of uropathogenic enterobacteria to gentamicin and ciprofloxacin has also been demonstrated by this author.

As part of our work, *Escherichia coli* showed the highest resistance to amoxicillin and great sensitivity rate with imipenem (89.65%). These results are consistent with those obtained by [17]. For *Klebsiella pneumoniae* strains, the highest resistance was observed with Amoxicillin and the lowest resistance rate was observed with Imipenem (6.25%). These results are similar to those of [11] in his study conducted in India. *Klebsiella pneumoniae* strains are naturally resistant to aminopenicillins due to the expression of Ambler class A chromosomal beta-lactamases (5), which could justify their high resistance to Amoxicillin. In Burkina Faso, [17] obtained a sensitivity rate for Imipenem that is similar to that obtained in this study.

The determination of the production of betalactamase by the double synergy test showed a general prevalence of 18, 44%. This prevalence is slightly below that [1]. In fact, they worked on the bacteria responsible for nosocomial infections at the zou-colline departmental hospital center. Strains of *Escherichia coli* (34.61%) are the most productive of betalactamase in our study followed by *Klebsiella pneumoniae* (30.77%). This resistance may be explained by a decrease in the activity of the beta-lactamase inhibitor (clavulanic acid), resulting from a penicillinase hyperproduction, or the inactivation of the inhibitor itself [14]. This is probably due to the often anarchic prescription of these molecules, especially in ambulatory medicine, pending ECU results.

In Benin, mathematical modeling has so far been little used in the fight against antibiotic resistance and therefore the literature on the latter is almost non-existent. Indeed, in a report published in 2014, WHO refers to Africa and South-East Asia as the regions of the world without antimicrobial resistance surveillance systems [13]. It is in this perspective that the present study was carried out. The results of this study therefore open a perspective for an estimate of the resistance rates of these strains by 2024.

## Conclusion

The present study has highlighted enterobacteria responsible for urinary tract infections in Benin and the increasing evolution of bacterial resistance to antibiotics which requires radical measures. Thus, before any suspicion of urinary infection, it is preferable to perform a Cytobacteriological Examination of urine with a mandatory antibiogram. Indeed, the antibiogram is above all a tool to help the therapeutic decision: by categorizing the sensitive bacteria, intermediate or resistant, it guides with predictability antibiotic therapy, contributing to a gain in morbi-mortality according to the severity of infections concerned. This will avoid the probabilistic or empirical treatment of the urinary tract infection responsible for resistance. Similarly, self-medication should be avoided by controlling the supply of antibiotics at the community and hospital level. Standard and specific hygiene precautions should also be followed to limit ESBLs. Awareness among health authorities, health professionals and the population is necessary for these measures to be understood and respected.

## Declarations

### Ethics approval and consent to participate:

The study has been submitted to the Benin National Ethical Committee for Health Research. An approval has been issued under the number N°65/MS/DC/SGM/DRFMT/CNERS/SA. The approval letter is available upon requested from the corresponding author. The respondents gave their verbal consent to participate in the study.

### Consent for publication:

All authors gave their consent for the publication of the manuscript.

## **Availability of data and material:**

All data generated or analysed during this study is included in this published article and supplementary information files.

## **Competing interests:**

Authors declare no competing interest.

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## **Authors' contributions:**

DV, AP, KH, AJ, KF and the Global Taskforce for AMR control consortium wrote the protocol, performed the study, designed the manuscript.

DV, AP and GJ-P performed the statistical analyses.

MFSR, LYE, KO, DL, DJ, BH, and LB-M reviewed the manuscript.

All authors have read and approved the manuscript.

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*Additional file: Figure S1: Appearance of champagne corks on MH agar; Figure S2: Variation of resistance among Escherichia coli strains between 2019 and 2024; Figure S3: Variation of resistance among Citrobacter diversus strains between 2019 and 2024; Figure S4: Variation of resistance among Enterobacter aerogenes strains between 2019 and 2024; Figure S5: Variation of resistance among Enterobacter cloacae strains between 2019 and 2024; Figure S6: Variation of resistance among Klebsiella oxytoca strains between 2019 and 2024; Figure S7: Variation of resistance among Klebsiella pneumoniae strains between 2019 and 2024; Figure S8: Variation of resistance among Morganella morganii strains between 2019 and 2024*

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## Tables

**Table I. List of hospitals included in the study**

| Number | Name of hospitals                          |
|--------|--------------------------------------------|
| 1      | Bethesda's Area Hospital                   |
| 2      | Menontin's Area Hospital                   |
| 3      | Parakou-N'dali's Area Hospital             |
| 4      | Padre-Pio's Area Hospital                  |
| 5      | HZ Tanguieta's Area Hospital               |
| 6      | Departmental Hospital Center of Porto-Novo |

**Table II: List of antibiotics used in the study and their corresponding charges**

| Antibiotics                   | Abbreviations | Charge in µg |
|-------------------------------|---------------|--------------|
| Amoxicillin + Clavulanic Acid | AMC           | 30           |
| Amoxicillin                   | AMX           | 25           |
| Cefotaxim                     | CTX           | 30           |
| Aztreonam                     | AT            | 30           |
| Ertapenem                     | ETP           | 10           |
| Ciprofloxacin                 | CIP           | 5            |
| Gentamicin                    | GEN           | 10           |
| Ceftriazone                   | CRO           | 30           |
| Imipenem                      | IMP           | 10           |

**Table III:** Microscopic aspects of the elements present in the samples.

| Appreciations    |      |      |          |               |       |
|------------------|------|------|----------|---------------|-------|
| Elements         | Rare | Many | Numerous | Very Numerous | TOTAL |
| Epithelial cells | 12%  | 30%  | 40%      | 18%           | 100%  |
| Kidney cells     | 70%  | 20%  | 10%      | 00%           | 100%  |
| Crystals         | 45%  | 35%  | 15%      | 05%           | 100%  |
| Leukocytes       | 7%   | 10%  | 35%      | 48%           | 100%  |

**Table IV:** Resistance profile of different bacterial species to different antibiotics used.

| Bacteria             | Interpretation of the inhibition diameters | Class of Antibiotics |             |                |             |             |             |           |            |               |
|----------------------|--------------------------------------------|----------------------|-------------|----------------|-------------|-------------|-------------|-----------|------------|---------------|
|                      |                                            | Beta lactams         |             |                |             |             |             |           | Aminosides | Quinolones    |
|                      |                                            | Penicillins          |             | Cephalosporins |             | Monobactams | Carbapenems |           | Gentamicin | Ciprofloxacin |
|                      |                                            | Amoxiclav            | Amoxicillin | Cefotaxim      | Ceftriazone | Aztreonam   | Imipenem    | Ertapenem |            |               |
|                      |                                            | AMC                  | AMX         | CTX            | CRO         | AT          | IMP         | ETP       |            |               |
| <i>E. coli</i>       | Resistant (%)                              | 58.63                | 91.37       | 37.28          | 41.37       | 31.03       | 3.44        | 10.34     | 36.20      | 58.18         |
|                      | Intermediate (%)                           | 00                   | 00          | 12.06          | 13.8        | 17.24       | 6.90        | 12.06     | 8.62       | 3.45          |
|                      | Susceptible (%)                            | 41.37                | 8.63        | 50.66          | 44.83       | 51.73       | 89.66       | 77.6      | 55.18      | 38.37         |
| <i>K. pneumoniae</i> | Resistant (%)                              | 62.5                 | 93.75       | 29.2           | 44.7        | 27.1        | 6.3         | 31.2      | 27.1       | 41.7          |
|                      | Intermediate (%)                           | 00                   | 00          | 10.4           | 6.3         | 31.2        | 4.1         | 10.4      | 2.1        | 20.8          |
|                      | Susceptible (%)                            | 37.5                 | 6.25        | 60.4           | 24          | 41.7        | 89.6        | 58.3      | 70.8       | 37.5          |
| <i>E. cloacae</i>    | Resistant (%)                              | 50                   | 82.6        | 50             | 43.5        | 30.4        | 00          | 43.5      | 23.9       | 50            |
|                      | Intermediate (%)                           | 00                   | 00          | 17.4           | 6.5         | 32.6        | 6.5         | 6.5       | 6.5        | 10.9          |
|                      | Susceptible (%)                            | 50                   | 17.4        | 32.6           | 50          | 37          | 93.5        | 50        | 69.6       | 39.1          |
| <i>K. oxytoca</i>    | Resistant (%)                              | 53.3                 | 100         | 66.7           | 60          | 66.7        | 00          | 33.4      | 46.7       | 60            |
|                      | Intermediate (%)                           | 00                   | 00          | 00             | 00          | 00          | 00          | 13.3      | 6.6        | 13.3          |
|                      | Susceptible (%)                            | 46.7                 | 00          | 33.3           | 40          | 33.3        | 100         | 53.3      | 46.7       | 26.7          |
| <i>E. aerogenes</i>  | Resistant (%)                              | 54.5                 | 100         | 45.5           | 54.5        | 45.5        | 00          | 9.1       | 27.3       | 54.5          |
|                      | Intermediate (%)                           | 00                   | 00          | 00             | 9.1         | 18.1        | 00          | 00        | 18.2       | 9.1           |
|                      | Susceptible (%)                            | 45.5                 | 00          | 55.5           | 36.4        | 36.4        | 100         | 90.9      | 54.5       | 36.4          |
| <i>M. Morganii</i>   | Resistant (%)                              | 50                   | 100         | 00             | 50          | 50          | 00          | 100       | 50         | 50            |
|                      | Intermediate (%)                           | 00                   | 00          | 100            | 00          | 00          | 50          | 00        | 00         | 50            |
|                      | Susceptible (%)                            | 50                   | 00          | 00             | 50          | 50          | 50          | 00        | 50         | 00            |
| <i>C. diversus</i>   | Resistant (%)                              | 25                   | 75          | 25             | 25          | 00          | 00          | 25        | 25         | 50            |
|                      | Intermediate (%)                           | 00                   | 00          | 00             | 00          | 00          | 00          | 00        | 00         | 00            |
|                      | Susceptible (%)                            | 75                   | 25          | 75             | 75          | 100         | 100         | 75        | 75         | 50            |

Table V: Prevalence of the enterobacteria producing betalactamase.

|                               | Number of bacteria identified | Number of ESBL Bacteria | Total  |
|-------------------------------|-------------------------------|-------------------------|--------|
| Bacteria                      |                               |                         |        |
| <i>Escherichia coli</i>       | 74                            | 24                      | 24/74  |
| <i>Klebsiella pneumoniae</i>  | 58                            | 18                      | 18/58  |
| <i>Enterobacter cloacae</i>   | 52                            | 8                       | 8/52   |
| <i>Klebsiella oxytoca</i>     | 20                            | 2                       | 2/20   |
| <i>Enterobacter aerogenes</i> | 18                            | 1                       | 1/18   |
| <i>Morganella morganii</i>    | 05                            | 0                       | 0/5    |
| <i>Citrobacter diversus</i>   | 03                            | 0                       | 0/3    |
| Total                         | 230                           | 53                      | 53/230 |

## Figures

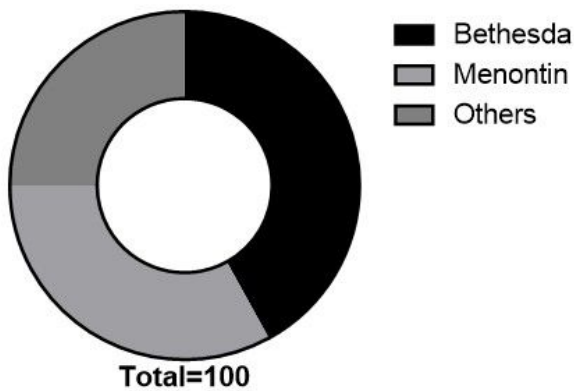


Figure 1

Percentage of urine samples according to the hospitals

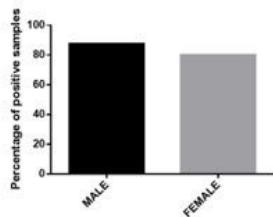


Figure 2a : Distribution of positive samples according to gender

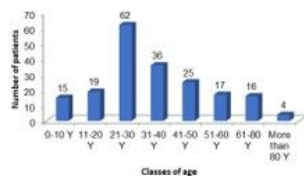


Figure 2b : Distribution of patients according to age

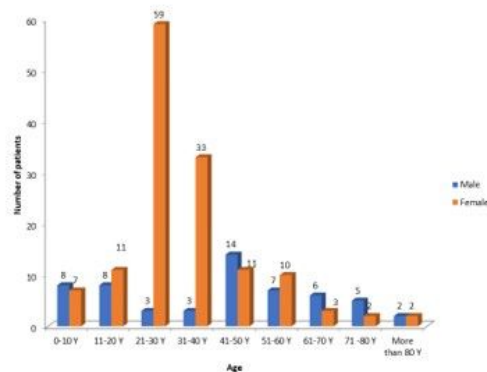


Figure 2c : Distribution of the study population following age group and gender

Figure 2

Socio-demographic characteristics of the population

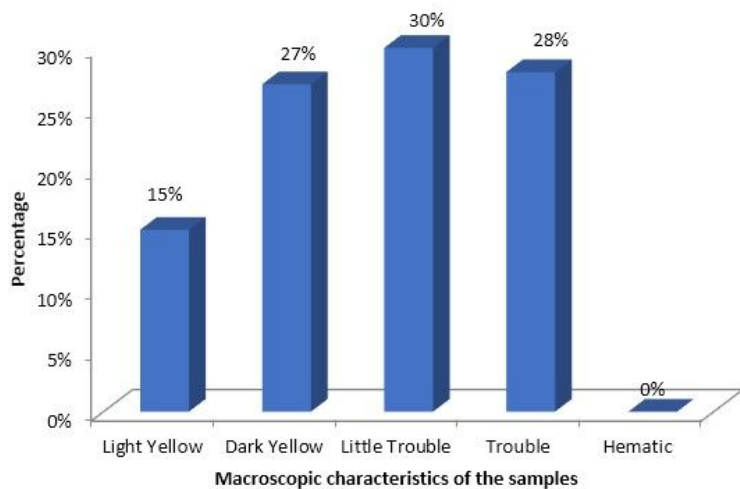


Figure 3

Macroscopic aspects of the samples collected

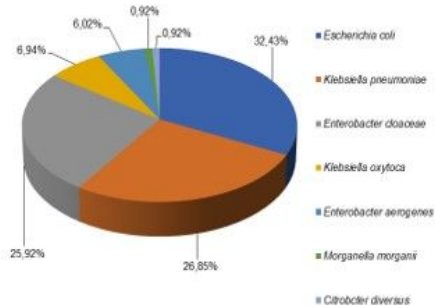


Figure 4a: Frequency of the species identified

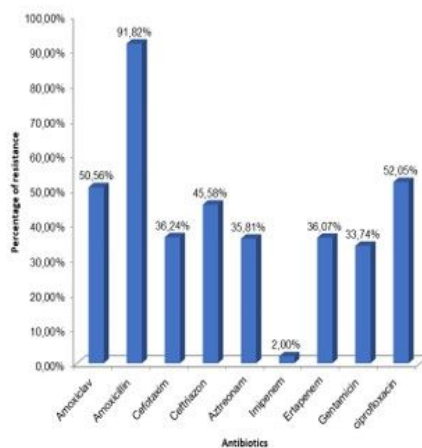


Figure 4b: Global resistance percentage of the enterobacteria to the antibiotics

Figure 4

Bacteriological characteristics of enterobacteria

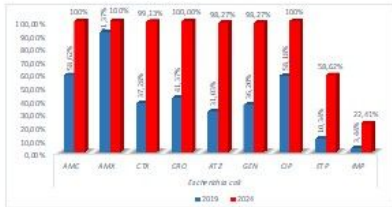


Figure 5a: Evolution of the resistance of *Escherichia coli*



Figure 5b: Evolution of the resistance of *Klebsiella pneumoniae*

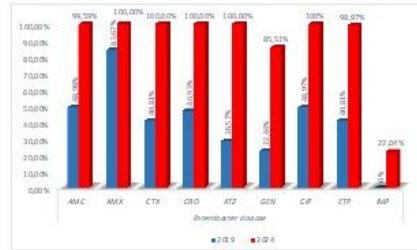


Figure 5c: Evolution of the resistance of *Enterobacter cloacae*

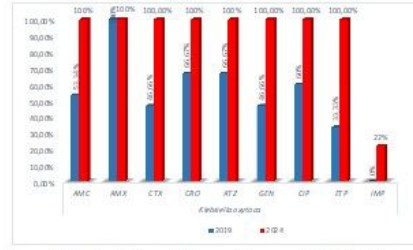


Figure 5d: Evolution of the resistance of *Klebsiella oxytoca*



Figure 5e: Evolution of the resistance of *Enterobacter aerogenes*



Figure 5f: Evolution of the resistance of *Morganella morganii*



Figure 5g: Evolution of the resistance of *Citrobacter diversus* strains

Figure 5

Evolution of the resistance among enterobacteria till 2024 through a modelisation approach

## Supplementary Files

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