COMPUTATIONAL SIMULATION OF WATER CONSUMPTION

BY

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THESIS

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ABSTRACT

Water characterizes and guarantees the continuity of life, which is an essential liquid, however, with the advancement of technology and the lack of information regarding its preciousness, it continues to be spent deliberately without measuring the consequences for future generations and for other forms of life. Aiming at this problem, the present work proposes, through mathematical calculations applied computationally, the visualization of water consumption scenarios, facilitating an interpretation through graphics, in a way that favors a more ethical reflection and with less environmental impact on consumption.

Keywords: Computer Simulation. Probability. Statistics. Markov processes. Water.

ACKNOWLEDGMENTS

This work and all that it represents is dedicated to my mother, the one who believed in my dream first. It is also dedicated to my father who unfortunately could not see me get this degree, but supported me the most in my first steps. I dedicate this to my friends, Daniel Orfeu, Flávio Santana and Leonardo Oliveiro, that made this long process more fun and easy. To the relatives that also supported me. To the professors who taught me everything so I could be able to accomplish this. To my advisor and professor Manuel Martins for believing in my idea for this work and for all the excitement about it. Finally, I dedicate this to the animals, to our planet and to all human beings.

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CHAPTER 1:

1.1 CONTEXT

This work has the purpose of through mathematical calculations applied on a computer to simulate scenarios of water consumption. The result here presented makes feasible future predictions of the remaining stock of this precious and essential resource and also proposes a more ethical and responsible reflection about this subject important for all kinds of life of the planet. The main goals includes:

- To use consumption models that can be applied as scenarios in a simulator;
- To create a computational structure that is capable of showing results of the scenarios;
- To generate simulations that allow an interpretation of the applied data facilitating a conclusion about the future of the planet.

It is an empirical knowledge that for all life, animal or plant being, water is a crucial resource and as it will be shown as statistical data in the next chapters, it is more scarce than what is popularly known. Therefore, the elaboration of this work aims to elucidate subjects related to the consumption of water, using a computational modeling of scenarios. The results interpretation suggests the adoption of policies of consumption that would be preferable and more ethical.

1.2 CHAPTER DISTRIBUTION

In the first chapter there is a brief context of the problem and how it will be approached in this document, as well as the chapter's description. In the second chapter it is explaining the variables that will be used on the algorithm, such as demographic layout, water consumption and composition on the planet, population growth, etc. In the third chapter it is explained the concepts of computational simulation, it's definitions and categories, as well as the reason for the chosen model for this work. In the fourth chapter we dive deeper on Markov Processes explaining better it's characteristics and concepts. In the fifth chapter the previous given values are applied in detail mathematically in the Markov Process. In the sixth chapter are presented the received results of the simulator, as well as the interpretation of the values and graphs. Finally there is the conclusion and ideas for a future improvement of this work. This document is divided in four steps:

- Explaining the computational simulation concepts;
- Building the scenario models using data from governmental sources and books;
- Applying the data on an algorithm that simulates the consumption;
- Interpreting the results.

In the explanation phase, the types of computer simulation and the methodology used in this work are described. In the model construction phase, data from official publications of water consumption and population were used. Such data provides subsidies for the creation of the mathematical model more adherent to reality. Additionally, scenarios for water consumption were designed considering a range of possibilities, from the most favorable to the most adverse. After completing the construction phase, the scenario simulation phase was initiated using a simulator built in Python programming language. Then the scenarios obtained were interpreted.

CHAPTER 2

2.1 WATER DISTRIBUTION AND DEMOGRAPHY

This chapter presents the mathematical inputs of consumption of the studied resource, as well as the link between this and the amount of population, establishing a bridge that enables an interpretation of the scenarios.

2.2 COMPOSITION OF WATER ON EARTH

Scientists have estimated that the total amount of water present in our globe matches the impressive number of 1.260.000.000.000.000.000.000 liters — a sextillion two hundred and sixty quintillion liters (Quantidade de água no planeta. MRV, 2013. Disponível em: <url>. Acesso em: 31 de outubro de 2020). All over the world, it's estimated that 97,5% of water is salty, therefore, it can not be consumed by humans directly or indirectly or in agriculture and livestock. About the remaining 2,5% of fresh water, 69% is hard to access, because it is located in solid state in the glaciers in the extreme poles. About 30% of this amount is found underground, in aquifers, and the remaining 1% in rivers. In other words, translating these percentages into numbers: we have the total of 9.765.000.000.000.000.000 liters (nine quintillions seven hundred and sixty five quadrillion liters) available to our consumption.

According to the United Nations for Food and Agriculture, 70% of all water consumed is used on agriculture and livestock. Besides that, almost the half of it is wasted (ANA, 2019. Disponível em: <url>. Acesso em: 24 de julho de 2020). If the water footprint of the meat is tracked, for example, it shows that to produce 1 kilogram of meat it spends an impressive amount of 16 thousand liters of water, and this amount corresponds to an adult person's total need for four months. As stated by the United Nations, each person needs 3,3 thousand liters of water a month, which means 110 liters of water is used on a daily basis to accomplish the higiene and consumption necessary, however, in Brazil, the consumption per person can reach more than 200 liters a day (Em Casa. Sabesp. Disponível em: <url>. Acesso em: 24 de julho de 2020). The UN also explains that livestock is the biggest consumer of water resources and, therefore, the ones that consume meat daily demands an amount of 4 thousand liters.

2.3 The water consumption

In this work, the brazilian consumption of water will be used. Per capita consumption is the average water consumption per day of a person, this amount of water used by individuals can be expressed in liters per habitant by day, in other words, it can be explained through the equation L/hab.day. Marcos Von Sperling (1996) has determined common values of per capita consumption, these values are shown on the table below. The first column defines a sampling of population and the second defines de water in liters for each habitant by day.

Variety of population	Per capita consumption - L/hab.day
< 2.000	130
2.000 - 10.000	125
10.000 - 50.000	133
50.000 - 120.000	128

Tabel 1: Variety of population and per capita consumption.
MAGALHÃES, C.A.C.; MORENO, J. e GALVÃO, A.C.G. **Estimativa do consumo per capita em comunidades atendidas pela unidade de negócio do médio Tietê. In: Congresso Brasileiro de Engenharia Sanitária e Ambiental**, 21, João Pessoa. Anais eletrônicos do 21º Congresso da ABES. Rio de Janeiro: ABES, 2001. Disponível em: <url> Acesso em: 25 fev. 2008.

2.3 Population Growth

According to the Data World Bank website (Population, total. Data World Bank. Available at: <url>. Accessed on: November First, 2020), the world wide population is almost 8 billions and the population grows 1,2% every year (FRANCISCO, Wagner de Cerqueira e. "O crescimento populacional no mundo "; Brasil Escola. Disponível em: <url>. Acesso em 17 de agosto de 2020), however, the life expectancy is expanding since the medical care avances, sanitation, etc.

CHAPTER 3

3.1 COMPUTATIONAL SIMULATION CONCEPTS

This chapter is about the simulation concepts and fundamentals, such as its classifications and the chosen model applied in this work.

3.2 COMPUTATIONAL SIMULATION AND ITS USE

The computational simulation consists in the application of statistical and mathematical techniques, using programming languages or specific programs for this kind of work, aiming to reproduce some process from reality, from nature point of view or industry. Through previous modeled scenarios it is possible to calculate and predict the behaviour of real systems. With this tool it is also practicable to make decisions and observe events that would our would not happen and with that information it's possible to think about a decision. This process has as the main advantage the possibility of pointing out a behavior without waiting for it to happen, in other words, decisions can be made taking this information as something relevant that we would not know at first. The scenarios do not need a big amount of data to bring out a result, the scenarios experimentation can be made in a determined time.

The main disadvantage is the fact that the given output is not exact, although it is possible to use metrics to assess any discrepancies or to stress the implementation testing until the results are close to the desired one. Another decisive factor is the quality of the input data, since it is determinant to guarantee the confiability of the outputs.

3.3 Simulation Categories

The categories can be classified according to some criteria. It will show three kinds and the difference between each one. It will also show the reason for the choice of the model applied in this work.

3.3.1 Static and Dynamic

The static models can be defined through the representation of models in a system where time is not taken as a determinant factor to the inputs. One example of this kind of simulation is the Monte Carlo model, used in engineering, science and financial areas. On the other hand, the dynamic model applies the evolution using time as an important factor. The example of a dynamic model could be the population growth, since the population is a value in a time x and another in a time $x+1$.

3.3.2 Deterministic and Stochastic

A deterministic model is when its evolution throughout the time is defined by its first condition. These models do not consider random elements and can be solved with mathematical analysis. The stochastic models can evolve through random element insertions obtained from extraction of statistical distributions.

3.3.3 Continuous and Discrete

The continuous models are used to represent systems that has its observed data changing continually as a time function, for example, a bicycle in a street can have its velocity and position changed in a time x. The discrete models occur as an event and state system. When events happen a state has its value changed and the system can stay at this state or change it to another.

3.4 The chosen project model

The reason why in this work the Markovian Decision Process will be used is due to the fact that this model is stochastic and occurs in a discrete time. In that way, it accepts extractions of random distributions, and because it happens in a discrete time it handles events and the change that occurs in the states of the processes of the events. It is possible to observe scenarios and events that happen with each chosen probability distribution, simplifying the application of the possibilities and the interpretation of the results.

CHAPTER 4

4.1 MARKOV DECISION PROCESS CONCEPTS

The Markov Decision Process (CIABURRO, 2020) is used in situations where the results are partially random and partially defined by the decision process, in other words, deterministic. This process occurs in a discrete time the same way a stochastic process is characterized by its states and actions.

Each chosen action leads to a random answer that brings a new state, in this transition between states a reward is received where the decision maker will evaluate its choice according to the implemented criteria. Especifically, a process is Markovian when the future state of the process depends on the observed instance, the present, and never on the past events.

4.2 MARKOVIAN PROCESS CHARACTERISTICS

The Markovian process is characterized by an Agent and an Environment aiming to achieve a goal. The Agent is the element that pursues the goal and the Environment is the element where the Agent interacts with. The agent can know, can not know or know partially an environment. The main characteristics of an agent:

- Constantly interacting with the environment, which causes changes of state in the environment during this interaction;
- The available actions can be continuous or discrete;
- The choice of action by an agent depends on the state of the environment and that choice requires a certain intelligence;
- The agent has a "memory" of the choices previously made.

The agent basically uses a trial and error strategy, where a memory of the errors that were made during the process is kept in order to obtain a satisfactory result.

4.2.1 Agent Policy

A policy determines an agent's behavior in relation to decision making. It is a fundamental part of the Markovian process, as it determines the agent's behavior. A policy is called optimal when it provides a high expectation between possible actions and in this way the agent does not need to keep the actions taken in memory, as he only needs to execute in the current state to reach his goal.

4.3 Markov Chains Introduction

Markov chains are discrete, finite and dynamic systems that exhibit characteristics of the Markovian process. The transition between states occurs in a probabilistic format, where the system evolves so that the past affects the future only through the present. As mentioned, a process is Markovian if its evolution depends on the current value of the state, that is, the state after n steps. We can represent this process through the following equation, where a random process is characterized by a sequence of random variables $X_0, \ ..., \ X_n$ with values given in a set $j_0, j_1, \ ..., \ j_n$.

$$P(X_{n+1} = j|X_0 = i_0, \ ..., \ X_n = i_n) = P(X_{n+1} = j|X_n = i_n)$$

A Markov chain occurs when a process X, being that stochastic and with discrete states, has a Markovian property, that is, the next state depends only on the current state, never on the sequence that precedes it. A Markov chain is homogeneous if the following transition probability does not depend on step n, but only on i and j only:

$$P(X_{n+1} = j|X_n = i)$$

In this hypothesis we can assume the following:

$$p_{ij} = P(X_{n+1} = j | X_n = i)$$

The joint probabilities can be calculated when we know the **pij** numbers and the following initial distribution:

$$p_i^0 = P(X_0 = i)$$

This probability represents the distribution of the process at zero time.

CHAPTER 5

5.1 ASSUMING VALUES TO THE CONSUMPTION MODELS

As previously seen, the Markov processes are very flexible models that allow probabilistic values to be assumed so that a result is predicted, that is, in this model it is allowed to adhere probabilities in order to observe a given desired behavior, as it will be better explained in the next topics. The model used in this work assumes that tomorrow's consumption will be affected by current consumption conditions, thus applying the Markovian concept.

The adopted model also considers that the population variable represents the general consumption of the resource. In other words, the value of consumption depends essentially on the quantity of the population.

Thus, the states of the adopted model represent population values over time. This work was first written in Portuguese, so the acronyms were created also in this language, but the logic does not change. A first scenario will have the following transition matrix between states, where:

CA = current population scenario;

PA = population increases;

PD = population decreases.

This matrix defines the return of conditional probability P (A | B), which indicates the chance that an event of A will occur after event B has occurred.

$$P = \begin{bmatrix} CACA \mid CAPD \mid CAPA \\ PDCA \mid PDPD \mid PDPA \\ PACA \mid PAPD \mid PAPA \end{bmatrix}$$

That is, this matrix has the following probabilities:

In the first line = P (Current Scenario | Current Scenario); P (Current Scenario | Pop Decreases), P (Current Scenario | Pop Increases);

In the second line = P (Pop Decreases | Current Scenario); P (Pop Decreases | Pop Decreases); P (Pop Decreases | Pop Increases);

In the third line = P (Pop Increases | Current Scenario), P (Pop Increases | Pop Decreases), P (Pop Increases | Pop Increases)

Since Markovian processes are stochastic models and, as previously discussed, accept values that can be chosen without a defined rule, we can therefore assume the following initial probabilities.

$$P = \begin{bmatrix} 0.05, 0.02, 0.93 \\ 0.18, 0.80, 0.02 \\ 0.05, 0.02, 0.93 \end{bmatrix}$$

The following diagram illustrates the transition of states and their values:

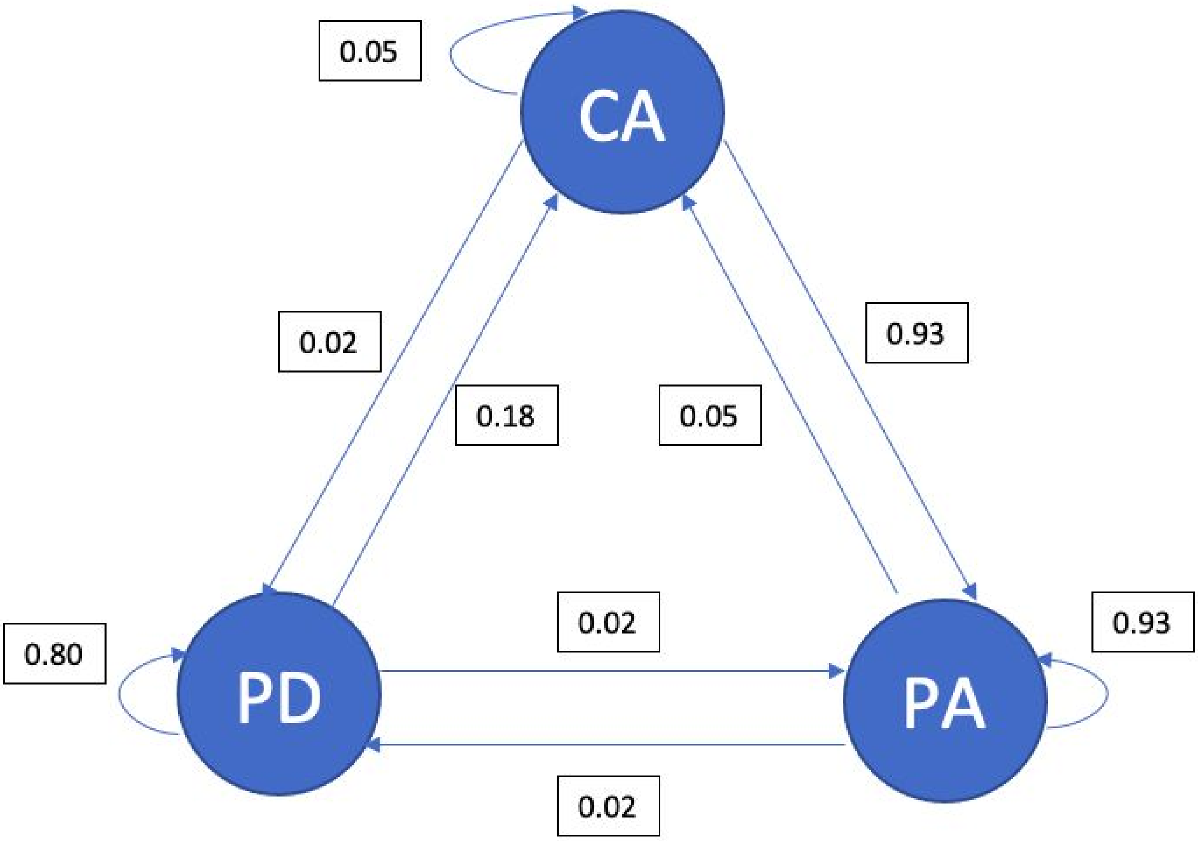

Figure 1: State diagram. Source: Elaborated by the author herself.

In this probability matrix we can understand that there are three scenarios: CA, PA and PD. In the first line we understand that, in this P probability matrix, there is a 5% chance of a scenario going from CA to CA, a 2% chance of going from CA to PD and a 93% chance of going from CA to PA. In the next line, it is understood that there is an 18% chance of a scenario going from PD to CA, an 80% chance of going from PD to PD and 2% of going from PD to PA. The bottom line shows that there is only a 5% chance of a scenario going from PA to CA, a 2% chance of going from PA to PD and finally a 93% chance of going from PA to PA.

This matrix shows the return of conditional probability P (A | B), which indicates the probability of event A occurring after event B has happened. In this matrix, in addition to the values being positive, the sum must be equal to 100% since it is a probability matrix of complementary events. In this model, the hypothesis that the vegetative growth of the population is a historical and permanent trend is also considered. However, one can simulate events in which the population remains constant or decreases. Applying these values in the code we will have:

```
np.random.seed(3)
States = ['CA','PD','PA']

TransitionStates = [['CACA','CAPD','CAPA'], ['PDCA','PDPD','PDPA'], ['PACA','PAPD','PAPA']]
TransitionProbabilities = [[0.05,0.02,0.93],[0.18,0.80,0.02],[0.05,0.02,0.93]]
```

Figure 2: Values applied in the code. Source: Elaborated by the author herself.

We also have the line np.random.seed (3), this function initializes the seed of the random number generator, so the simulation will be reproducible and the experiment will be guaranteed by the fact that the numbers generated will always be the same.

5.2 CONSUMPTION VARIABLES

For the application of the distribution signaled in the previous item, population values, available amount of water, daily consumption per person and water footprint of one of the foods that most consumes water were used.

5.2.1 Population quantity

According to the World Bank (Population, total. Data World Bank. Available at: <url>. Accessed on: November 1, 2020), in 2019 the world population reached about 7.6 billion.

5.2.2 Amount of water available for consumption

As previously calculated, there are about 9 quintillions and seven hundred and sixty-five quadrillion liters of drinking water.

5.2.3 Amount of daily consumption per person

As pointed out in topic 2.3 of Chapter 2 on daily consumption per person, the highest consumption value, i.e. 133 liters per person per day, will be taken into account. Although in many places in Brazil this consumption exceeds 200 liters per person (Em Casa. SABESP. Available at: <url>. Accessed on: November 15, 2020), in this model, however, we will use the value of 133 liters / person.

5.2.4 Tracking the water footprint of meat

It is estimated that only 5% of the world population is vegetarian (What would happen in the global economy if everyone were to become vegetarian. G1. Available at: <url>. Accessed on: August 17, 2020), so it will be taken into account also the consumption of foods that cause greater environmental impact, such as meat. According to the Vegan Calculator website (The Vegan Calculator. Vegan Calculator. Available at: <url>. Accessed on: October 31, 2020), a person who consumes meat daily also uses 4,164 liters of water.

5.3 Applying consumption mathematically

This work considers for population demonstration and comparison purposes two population scenarios: people who eat meat and people who do not eat meat.

In this way, it will be possible to display the disparity in consumption for each scenario, which naturally brings the possibility of a reflection on more ethical consumption. As noted earlier, an individual who consumes meat has a daily expenditure of 133 liters of water, plus an additional 4,164 liters of water from the meat feed, totaling 4,297 liters daily and 1,568,405 liters in one year.

The individual who chooses to eat only vegetables and grains saves the more than 4 thousand liters mentioned above, therefore, in this model, this individual will have a daily expenditure of 133 liters of water and a total of 48,545 liters in one year. The following table shows these values:

Water Consumption	Average Daily	Daily with meat	Daily Total	Anual
With Meat	133	4164	4297	1.568.405

Vegan	133	0	133	48.545

Table 2: Consumption for the vegan and carnist population[1].

With these values we can understand that there is a 3131% variation in consumption between the vegan individual and the meat consumer. In the same way that we can observe that the annual consumption of the vegan does not reach 4% of the value of the carnist.

```
consumptionWaterCarnistList = list()
consumptionWaterVeg = list()
scenariosList = list()

NumDays = 58400  #160 anos
TodayState = States[0]

QuantityWaterAvailableCarnist = 976500000000000000
QuantityWaterAvailableVeg = 976500000000000000

Population = 7600000000

PopulationGrowthTax = 0.012
PeopleIncreaseByDay = 0

quantityDailyWaterConsumedVeg = 133
quantityDailyWaterConsumedCarnist = 4297

totalDaysCA = 0
totalDaysPD = 0
totalDaysPA = 0
```

Figure 3: Values applied in the code. Source: Elaborated by the author herself.

These values are then displayed in the code, where lists of consumption, scenarios and population are created, so that the simulation is visualized in the form of graphs, as will be verified in the next chapter. The simulation will be observed for a total of 160 years, that is, 58400 days. As the Markov process needs an initial value, as previously mentioned, the initial state is also defined. The total value of the water is arranged, as well as the population, quantity of water by type of population and the rate of increase.

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[1] *Carnism was a term conceived by social psychologist Melanie Joy that defines an invisible belief system or ideology that justifies the death of some species of animals for consumption of their meat.

CHAPTER 6

6.1 EXPLAINING THE USED TECHNOLOGY

Having obtained the mathematical inputs necessary to understand the functioning of the Markovian model, as well as the formal definition of a computational simulation and its characteristics, this chapter discusses the implementation of the model used to simulate the scenario and the results obtained. The generated graphics facilitate the interpretation of the results obtained with the application of the model.

The programming language used was Python 3, on a MacBook Air 2017 computer, 1.8GHz Dual-Core Intel Core i5 processor, 8GB DDR3 1600MHz, Intel HD Graphics 6000 1536MB graphics card, macOS Catalina operating system.

6.2 APPLICATION OF THE ALGORITHM

After importing the necessary libraries and the inputs that will be used filled in, functions are created for manipulating the population, which are:

```
def populationIncrease(PopulationTotal):
  return PopulationTotal + PeopleIncreaseByDay

def populationDecrease(PopulationTotal):
  return PopulationTotal - PeopleIncreaseByDay

def totalPeopleByDayWithRate(Population):
  IncreasePeopleAnnual = Population * PopulationGrowthTax
  PeopleIncreaseByDay = IncreasePeopleAnnual / 365

  return PeopleIncreaseByDay
```

Figure 4: Population manipulation functions. Source: Elaborated by the author herself.

The functions for the consumption of each type of population are created below and also the variable *PessoasAumentoPorDia* is filled in for the initial population rate, that is, for the first year.

```
def waterConsumptionCarnist(Population, quantityWaterAvailable):
  return quantityWaterAvailable - (quantityDailyWaterConsumedCarnist * Population)

def waterConsumptionVeg(Population, quantityWaterAvailable):
  return quantityWaterAvailable - (quantityDailyWaterConsumedVeg  * Population)

PeopleIncreaseByDay = totalPeopleByDayWithRate(Population) #first year rate
```

Figure 5: Consumer functions. Source: Elaborated by the author herself.

Finally, a loop is created starting from day one until the day NumDias, where the forecast of the current day is checked and for each state, through the function np.random.choice (), a condition is generated randomly, or that is, random samples are returned through an array, this TransitionStates [x] being the first parameter. The second parameter defines whether the sample is replaced or not. Finally, the third parameter explains the associated probability for each array entry.

```python
for i in range(NumDays):
  if TodayState == 'CA':
    Condition = np.random.choice(TransitionStates[0], replace = True, p = TransitionProbabilities[0])

    if Condition == 'CACA':
      totalDaysCA += 1
    elif Condition == 'CAPD':
      TodayState = 'PD'
      totalDaysPD += 1
      Population = populationDecrease(Population)
    elif Condition == 'CAPA':
      TodayState = 'PA'
      totalDaysPA += 1
      Population = populationIncrease(Population)

  elif TodayState == 'PD':
    Condition = np.random.choice(TransitionStates[1], replace = True, p = TransitionProbabilities[1])

    if Condition == 'PDPD':
      totalDaysPD += 1
      Population = populationDecrease(Population)
    elif Condition == 'PDCA':
      TodayState = 'CA'
      totalDaysCA += 1
    elif Condition == 'PDPA':
      TodayState = 'PA'
      totalDaysPA += 1
      Population = populationIncrease(Population)

  elif TodayState == 'PA':
    Condition = np.random.choice(TransitionStates[2], replace = True, p = TransitionProbabilities[2])

    if Condition == 'PAPA':
      totalDaysPA += 1
      Population = populationIncrease(Population)
    elif Condition == 'PAPD':
      TodayState = 'PD'
      totalDaysPD += 1
      Population = populationDecrease(Population)
    elif Condition == 'PACA':
      TodayState = 'CA'
      totalDaysCA += 1
```

Figure 6: Repeat loop and condition check. Source: Elaborated by the author herself.

Even within the repetition loop, the rate of population increase is updated every year, water is consumed for each type of population and these values are added to lists. At the end of the repetition, using the matplotlib.pyplot library, the graphics are generated.

6.3 Graphs and Interpretation of Results

When modeling the state diagram (Figure 1: State diagram, page 26) with the probabilities arranged for each event, we obtained the following arrangement of scenarios in a test that simulates 160 years, that is, 58400 days.

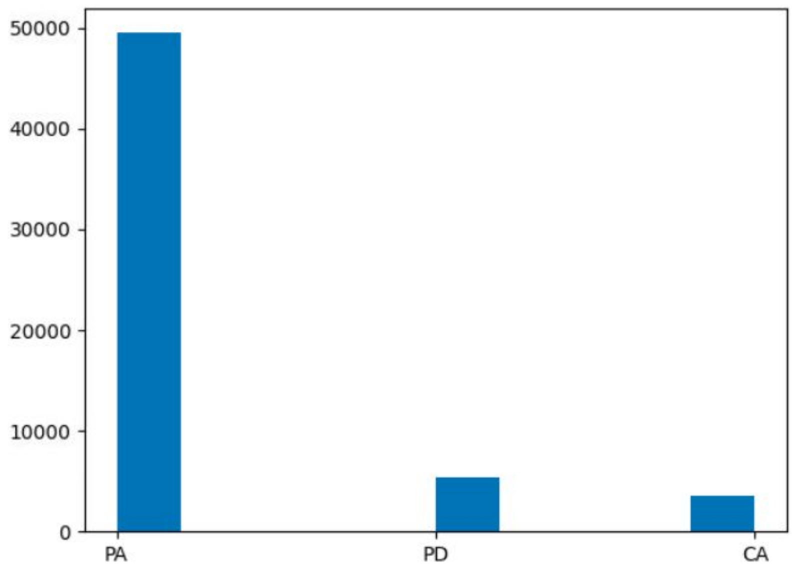

Figure 7. Scenario Histogram. Source: Elaborated by the author herself.

- Total days CA: 3490;
- Total days PA: 49524;
- Total days PD: 5385.

Next, a consumption graph was provided for the case of the population that consumes meat and a graph for the consumption of a vegetarian population. As much as the design is similar, the values are very different. The data displayed in line y of the graph (vertical) represents water consumption and how much it decreases as the days — line x (horizontal) — pass.

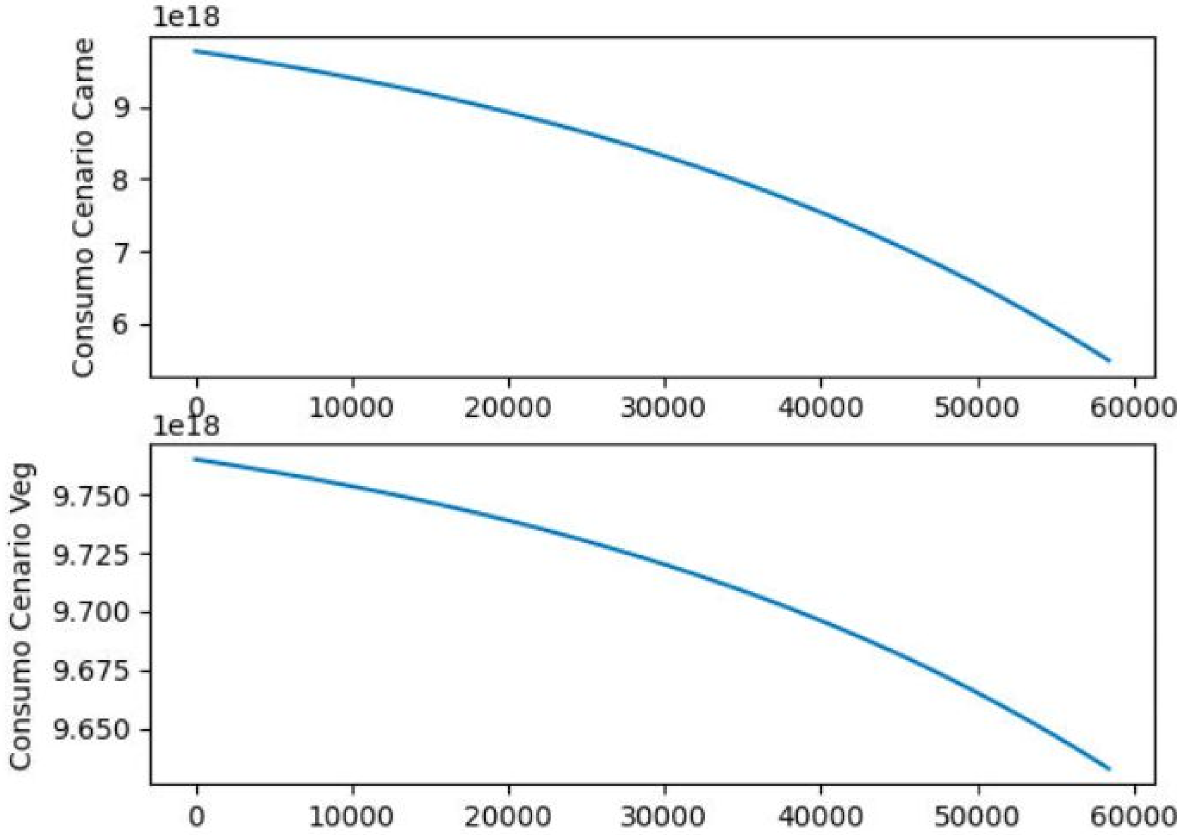

Figure 8. Comparison of Scenarios. Source: Elaborated by the author herself.

Before the graphs are shown, the values for the scenarios are displayed on the screen in numbers where:

- There is the total left over from the consumption of the carnist population (5,491,979,023,135,739,904 liters, that is, five quintillions and four hundred and ninety-one quadrillion);
- There is the total left over from the consumption of the vegetarian population (9,632,742,194,572,365,824 liters, that is, nine quintillions and six hundred and thirty-two quadrillions);
- How much the carnist population consumed in those years (4,273,020,976,864,260,096, that is, more than four quintillion liters);
- How much the vegetarian population consumed in those years (132,257,805,427,634,176, that is, one hundred and thirty-two quadrillion liters).

```
Total days CA:  3490
Total days PA:  49525
Total days PD:  5385


Amount of Water Available Carnist Scenario:  5491840001492313088
Amount of Water Available Veg Scenario:  9632737891598397440


Water Consumption Carnist Scenario:  4273159998507686912
Water Consumption Scenario Veg:  132262108401602560


Total Population:  32223700150
```

Figure 9. Console results. Source: Elaborated by the author herself.

In other words, we can see that in this scenario the population over 160 years had a total value of 24 billion people added.

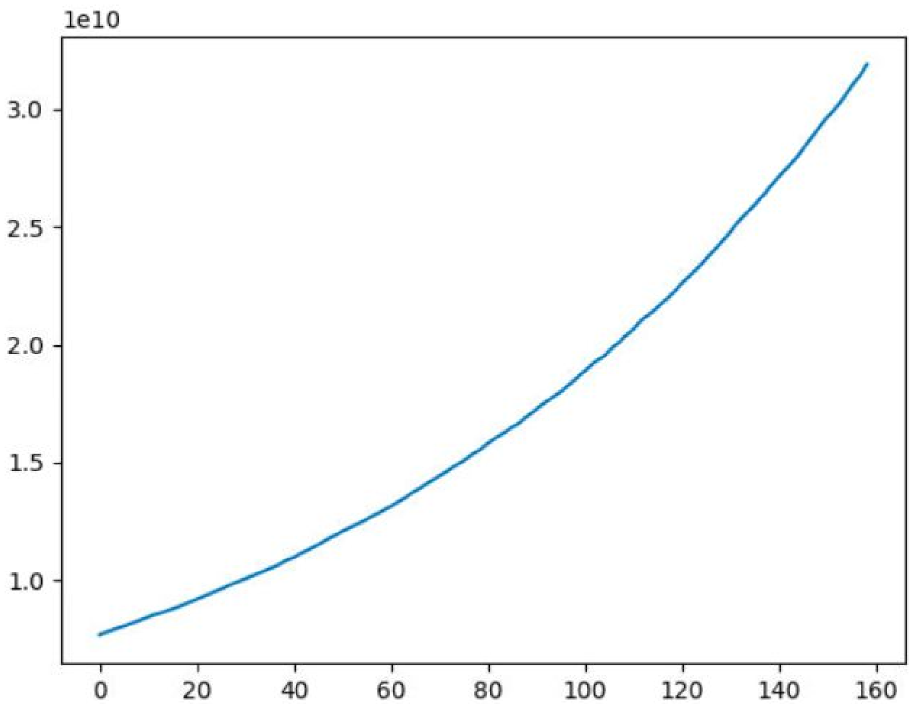

Figure 10. Population growth over 160 years. Source: Elaborated by the author herself.

In this graph, in line y of the graph (vertical), the population values are represented, initially with a total of 7 billion and as line x (horizontal) of the years pass, the line increases from 30 billion people.

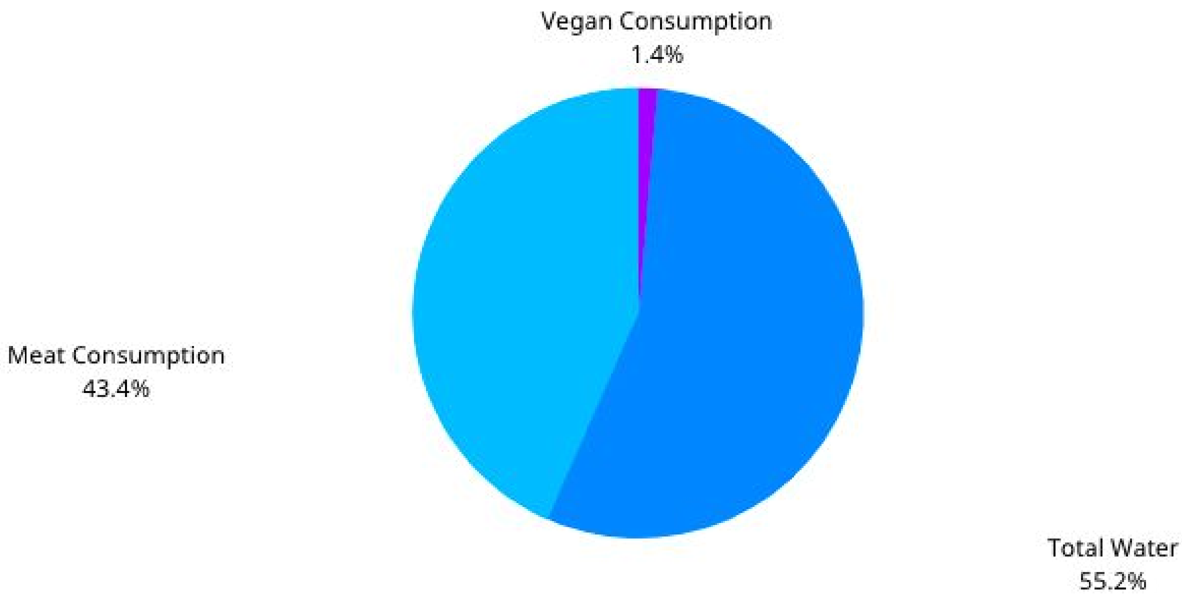

Figure 11. Consumption as a percentage. Source: Elaborated by the author herself.

We also observed that the meat-consuming population extinguished approximately 43.7% of the total water available, while the vegetarian population consumed approximately 1.4% of the total water available on the planet.

6.3.1 Applying one more scenario

As explained, the Markov processes allow for a range of flexibilities in terms of probabilistic values, so that a new scenario can be created so that we can assess the differences. Thus, the following probabilities were elaborated, in a more distributed way:

$$P = \begin{bmatrix} 0.2, 0.05, 0.75 \\ 0.2, 0.7, 0.1 \\ 0.3, 0.1, 0.6 \end{bmatrix}$$

We then have the following diagram of probabilities between states:

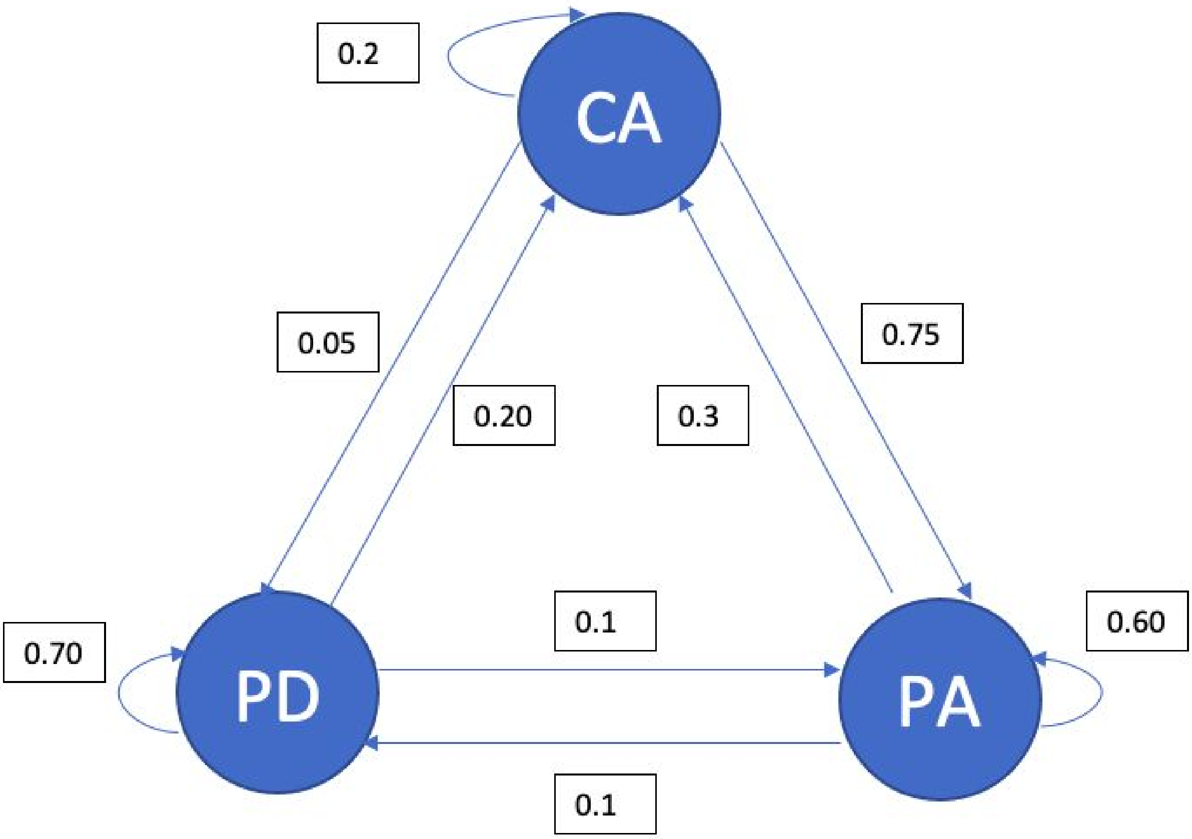

Figure 12. State diagram two. Source: Elaborated by the author herself.

Changing the odds directly in the code:

```
TransitionStates = [['CACA','CAPD','CAPA'], ['PDCA','PDPD','PDPA'], ['PACA','PAPD','PAPA']]
TransitionProbabilities = [[0.05,0.02,0.93],[0.18,0.80,0.02],[0.05,0.02,0.93]]
```

Figure 13. Application of values in the code. Source: Elaborated by the author herself.

When modeling this new state diagram (Figure 8. State diagram two, page 35) with the probabilities arranged for each event, we obtained the following arrangement of scenarios in a test that simulates 160 years, that is, 58400 days.

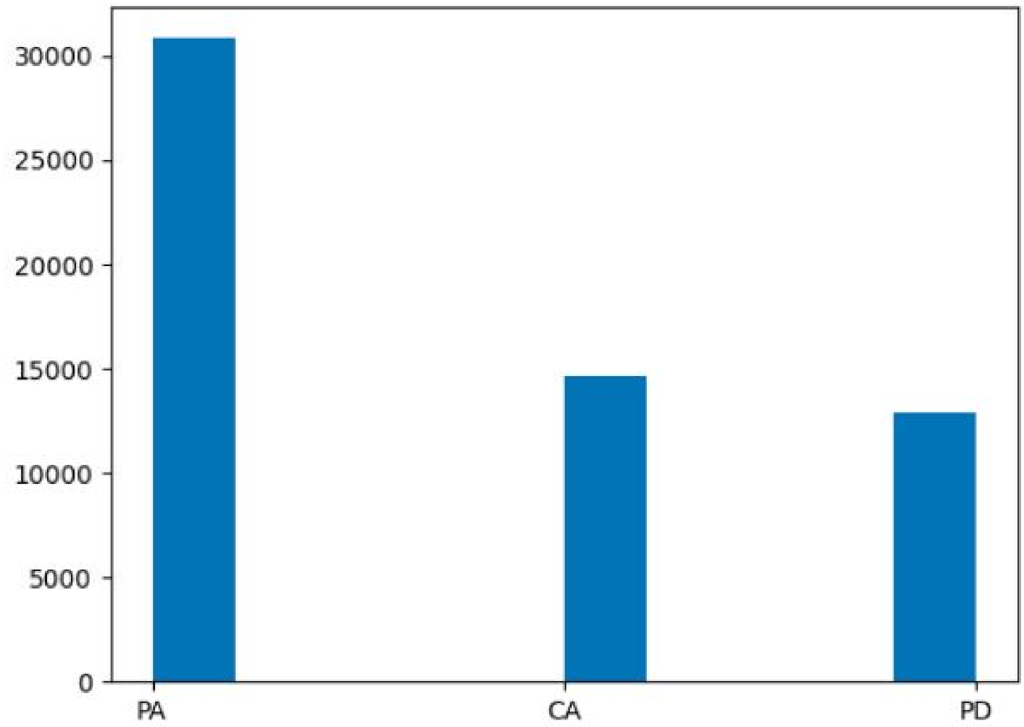

Figure 14. Histogram of total scenarios. Source: Elaborated by the author herself.

- Total days CA: 14646;
- Total days PA: 30853;
- Total days PD: 12900.

Next, a new consumption graph was provided for the case of the population that consumes meat and a graph for the consumption of a vegetarian population. Again, the design is similar, however, the slightly lower values are still outdated. The data displayed in line y of the graph (vertical) represents water consumption and how much it decreases as the days — line x (horizontal) — pass.

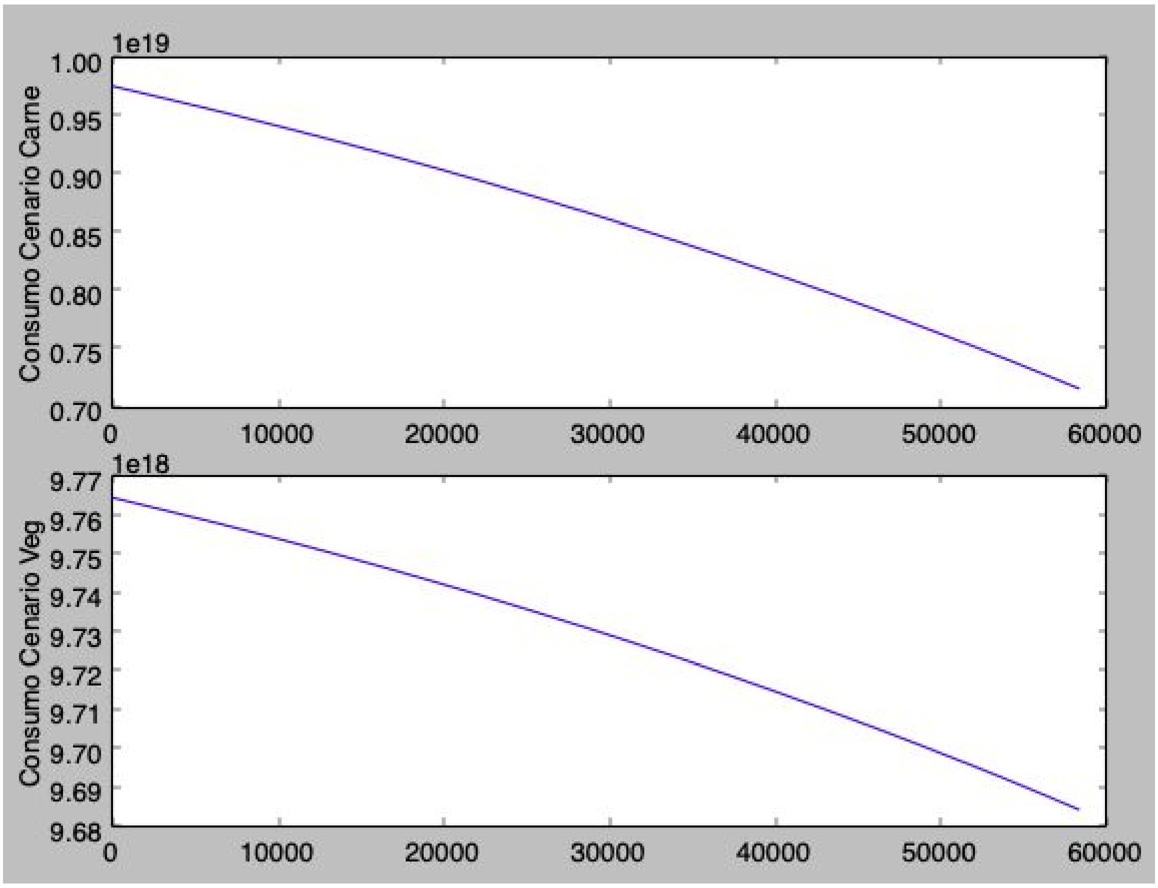

Figure 15. Water consumption in both scenarios. Source: Elaborated by the author herself.

The consumption data in the form of numbers is printed on the console:

```
Total dias CA:  14646
Total dias PA:  30853
Total dias PD:  12900


Qtd Agua Disponivel Cenario Carnista:  7169446615815401472
Qtd Agua Disponivel Cenario Veg:  9684662881057910784


Consumo de Agua Cenario Carnista:  2595553384184598528
Consumo de Agua Cenario Veg:  80337118942089216


Total populacao:  13697803617
```

Figure 16. Result of the console. Source: Elaborated by the author herself.

Where:

- The amount of water available in the carnist scenario is: 7,169,446,615,815,401,472 (seven quintillion and one hundred and sixty-nine quadrillion liters of water);
- The amount of water available in the vegan scenario is: 9,684,662,881,057,910,784 (nine quintillions and six hundred eighty-four quadrillion liters of water);
- Total water consumption in the carnist scenario was a total of 2,595,553,384,184,598,528 (more than two quintillion liters of water);
- And the total water consumption in the vegan scenario was a total of 80,337,118,942,089,216 (just over eighty quadrillion liters of water);
- The total population reached 13,697,803,617 (thirteen billion people).

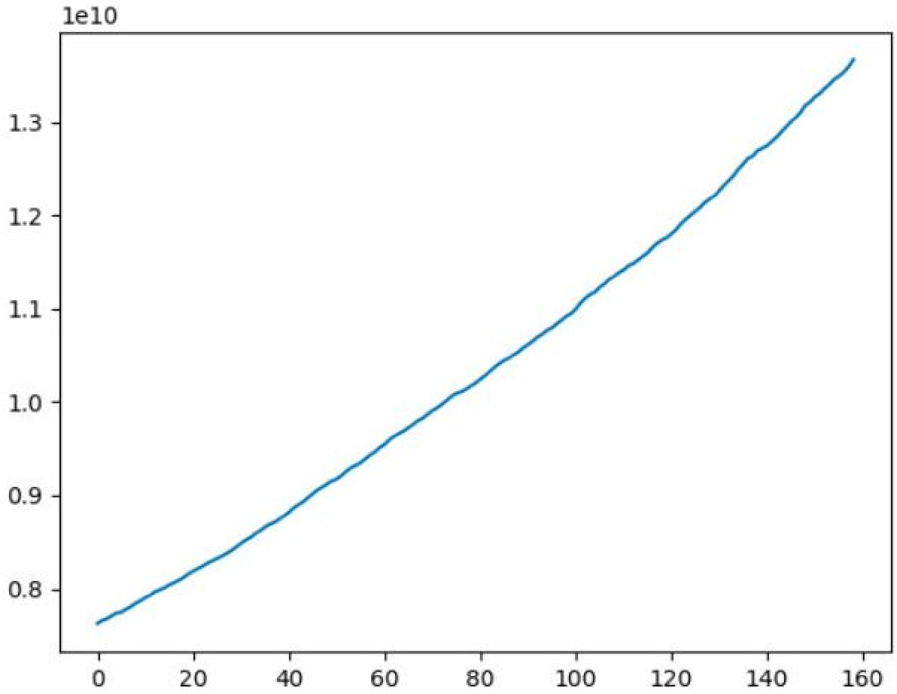

Figure 17. Population growth graph. Source: Elaborated by the author herself.

We also observed that in this scenario, the meat-consuming population extinguished approximately 27.3% of the total water available, while the vegetarian population consumed approximately 0.8% of the total water available on the planet.

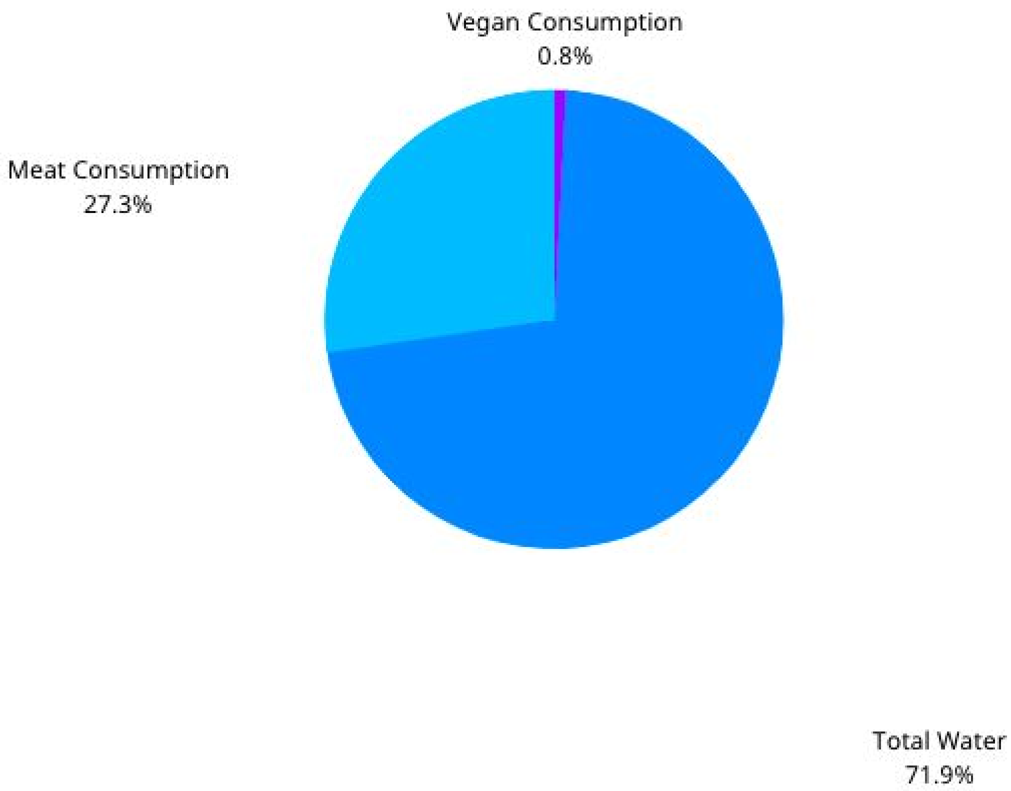

Figure 18. Population consumption graph. Source: Elaborated by the author herself.

CONCLUSIONS

The objective of this work was to carry out a parameterization of water consumption and bring reflection to the use of food from animals through a mathematical formula applied in a programming and computer language. Based on the bibliographic research carried out for this work, it is possible to clarify the small amount of drinking water available and how much it is wasted in this form of consumption, which in addition to being unethical has not proved to be optimal for the planet in the long run.

Through the scenario presented with the values applied to the assumed probabilities, one can have a glimpse of the impact on the resource and how different each scenario is demonstrated.

FUTURE WORKS

Aiming at the future of the work, a graphical interface is idealized that receives the values of the probabilities and the data that will be applied in the algorithm in a way that demonstrates, at the same page, statistics screens and histograms, even on the same page, without the need for see the code. An optimization in the speed of execution of the algorithm is also idealized, taking into account leap years, as well as a refactoring so that the code is more elegant and better disposed.

Project available at link: https://github.com/JoicePaz/tcc

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