Statistical Analysis and Evaluation of Drinking Water Consumption Needs in Dakar from 2016 to 2025

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Abstract In Dakar, a considerable deficit is observed in the distribution of drinking water. The demand for drinking water is increasing day by day and the available resources are insufficient. The objective of this article is first to assess the drinking water consumption needs of the Dakar region by performing a statistical analysis of the data. Statistical analysis of the data made it possible to assess the state of coverage of drinking water consumption needs. In addition, this statistical analysis will make it possible to make a comparison between the evolution of drinking water consumption needs and the current available resources. The results obtained show that after interpolations of the data by different polynomials (interpolation of degree 1, interpolation of degree 5, and interpolation of degree 10), the best interpolation in order to have an optimal projection of the evolution of drinking water consumption as a function of the population is the interpolation polynomial of degree 10. This equation called the Dakar equation which gives the consumption as a function of the population is as follows: $Cons = 8,959.10^2 Pop^2 - 5,2592.10^8 Pop + 1,382.10^{14}$.

Keywords: *drinking water, Dakar, evolution, perspective, consumption, needs, statistics, deficit*

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1. Introduction

Statistics will make it possible to analyze the data, in order to comment on or interpret the facts to which these data relate.

These are the data relating to the population and the consumption of drinking water.

These data will be presented in an appropriate manner to enable meaningful results to be determined and appropriate comments to be made.

The calculation of drinking water needs relates to the estimate of the workforce to be served, that is to say the population affected by the network and therefore the determination of any water needs.

To determine the current and future needs for drinking water, we must determine the needs for the resident population, the needs for public and social facilities without forgetting the needs for individuals.

We would therefore like to point out that the objective of the drinking water supply system is to meet as much as possible the water needs of the area concerned by the project for a well-defined period which is estimated as the lifespan of the network.

The water needs correspond to the supply that the operator will have to make available to meet user demand. Drinking water requirements are determined at each stage of the system by taking into account the users' drinking water demand, their behavior and the yields of the installations concerned [1].

Short, medium and long term water demand is calculated on the basis of average consumption or demand. It is made on the basis of specific average daily consumption and the results of surveys of institutional and socio-economic users.

Specific consumption and service rates were defined from consumption analyzes from the statistical file of SEN EAU (formerly SDE) and in conformity as far as possible with the Millennium Development Goals [2,3].

2. Materials and Methods

2.1. Data Acquisition

To assess the evolution of consumption, we develop graphs (curves) which give the consumption values in m3 / day according to the years (from 1997 to 2025). We will also determine the mean of the values and the standard deviation [4].

The latter allows us to learn about the dispersion of values around the mean.

Data analysis is necessary and consists of describing and exploring the data to derive some laws or predictive models.

Table 1. Population and consumption of drinking water in Dakar from 1997 to 2018

Years	Populations	Consumption in m3 / year
1997	2 016 009	47 141 396
1998	2 091 081	48 728 365
1999	2 168 498	49 649 123
2000	2 248 223	53 032 542
2001	2 330 236	58 921 426
2002	2 352 370	59 695 876
2003	2 361 260	61 217 126
2004	2 370 102	62 972 952
2005	2 391 550	64 316 985
2006	2 425 368	65 476 840
2007	2 428 155	67 849 724
2008	2 433 215	68 738 429
2009	2 466 359	72 424 522
2010	2 520 054	74 247 333
2011	2 704 635	76 141 934
2012	2 965 214	78 095 183
2013	3 137 196	77 301 115
2014	3 233 460	82 516 551
2015	3 330 692	100 604 676
2016	3 429 370	113 648 518
2017	3 529 300	114 075 201
2018	3 630 324	115 923 226

Thus, we have gathered the data relating to population and consumption from 1997 to 2018 in Table 1.

This table shows the population in number of inhabitants for each year from 1997 to 2018; but also the annual consumption in m3 from 1997 to 2018.

This table allows us to see how the population and consumption of drinking water in Dakar evolved during this period.

We were able to obtain 22 years of drinking water consumption data at the SDE level.

The latter did not want to provide data prior to 1996; date on which his affermage contract with the state of Senegal began.

All the data on the overall consumption of the Dakar region as well as data on the population from 1997 to 2018 are shown in Table 1.

From Table 1, we have established, using Matlab software, the point clouds of different polynomials (interpolation of degree 1, interpolation of degree 5, and interpolation of degree 10).

2.2. Data Processing and Analysis (Numerical Statistics)

The Dakar region is made up of four (4) departments (Figure 1).

The analysis and processing of digital data was facilitated by the Matlab software which allowed us to draw figures and curves; which will make it possible to derive the equations for the evolution of drinking water consumption in the Dakar region.
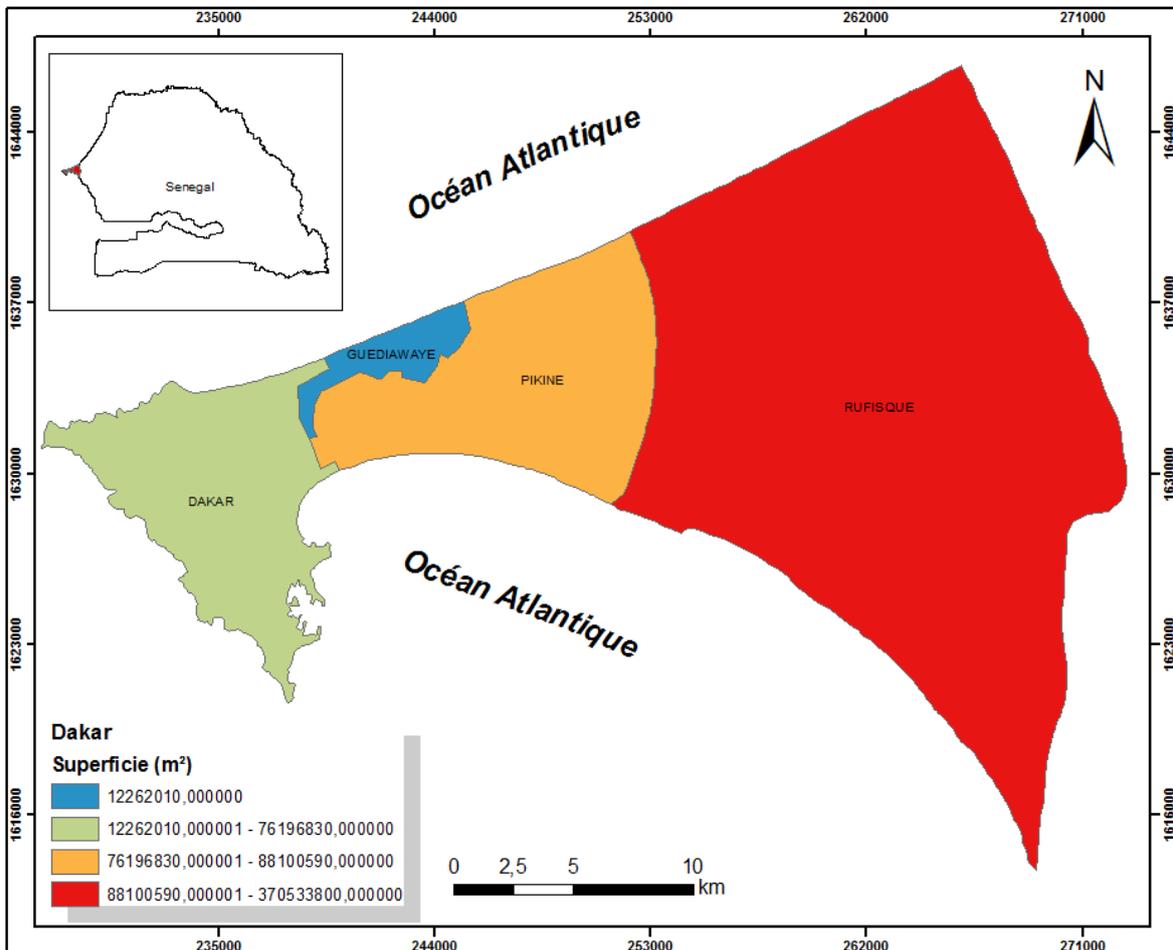
Figure 1. Departmental division of the Dakar region

Table 2. Assumptions for calculating the Terms of Reference for the Millennium Development Goals

SETTINGS	HYPOTHESES
Annual population growth (%)	The growth rate is that observed between the 2002 and 2013 censuses, or failing that the regional rate
SERVICE RATE OBJECTIVES: 100% in 2021 in urban centers (% pop):	
By BP (% Pop)	OMD in urban centers: 79% in 2015 in the regions and 88% in Dakar; 100% from 2021
By BF (% Pop)	OMD in urban centers: < 21% in 2015 in the regions and 12% in Dakar; 0% from 2021
Network performance	The target to be reached is 85% from 2022
BP specific consumption	= if consumption <50l/inhabitant/day: 50; value found)
Specific consumption BF	= if consumption <25l/inhabitant/day: 25; value found)
Daily peak coefficient	= value equal to 1.10 or 1.30 depending on the case Small centers: 1.30 (pop < 100,000 inhabitants) Large centers: 1.10 (pop > 100,000 inhabitants)
Hourly peak coefficient	= at or 2.2 depending on the case: Small centers: 2 (pop < 100,000) Large centers: 2.2 (pop > 100,000)

The assessment of drinking water needs was made on the basis of the calculation assumptions set out in the Table 2.

**Table 3. Distribution of the 14 centers in the different Regional Directorates (DR)**

Regional Directorate	Number of centers in the DR
DAKAR 1	05
DAKAR 2	05
RUFISQUE	04

For the situation of water supply sources, the Senegalaise des Eaux (SDE), linked to the State of Senegal by a contract, provides drinking water supply to populations in urban and peri-urban areas. It has Eleven (11) Regional Directorates and the Dakar region has three (03) in which the 14 centers of this study are attached as shown in Table 3 [5].

3. Results and Discussions

From Table 1, we established, using **Matlab software,** the point clouds and the regression line in Figure 2, which show how the population and water consumption in Dakar evolved from 1997 to 2018.
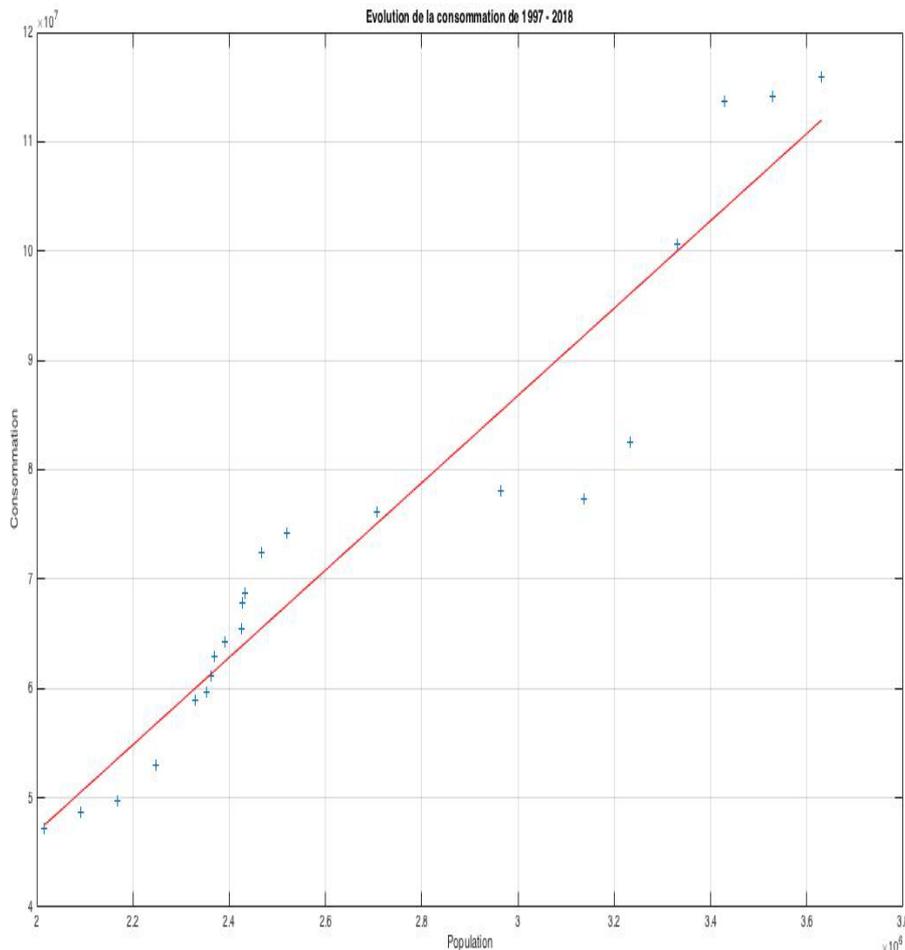
Figure 2. Curve of the consumption (m3) of drinking water compared to the population from 1997 to 2018 from the polynomial of degree 1 interpolation

Figure 2 shows a scatter plot of drinking water consumption versus population as well as the regression line.

The following expression allowed us to calculate the correlation coefficient between the population and the consumption of drinking water.

$$r(Pop\ Cons) = \frac{\text{cov}(Pop, Cons)}{\sqrt{Var(Pop)Var(Cons)}}$$

Thanks to this expression, we found a correlation coefficient **r (Pop, Cons) = 0.9559**.

This coefficient r (Pop, Cons) = 0.9559 is close to 1. So we have a good correlation. This strong correlation shows that population and consumption are linearly related.

Therefore, a functional relationship can be established between population and consumption. That is, find a function f such that Y = f (X).

The idea is to find a polynomial fit.

3.1. Approximation by an interpolation polynomial of degree 1.

We are trying to approach the point cloud on a straight line.

So, we can use a linear fit such that:

$$\text{Cons} = \alpha Pop + \beta \qquad (1)$$

Thus, thanks to the programming done with the Matlab software, we have the following values of α and β:

$$\alpha = 39,9237 = 40$$

$$\beta = -32\,974\,484,8524 = -3.10^7$$

In addition, we have output for the population as well as for the consumption of drinking water, the values of the mean, standard deviation and variance.

Standard deviation is a measure of the dispersion of values in a statistical sample or probability distribution. It is defined as the square root of the variance or, equivalently, as the root mean square of the deviations from the mean.

If the standard deviation is greater than 0.5 mean, we can therefore consider that the variations are strong.

These values (means, standard deviations, variances) are recorded in Table 4.

Table 4. Values of standard deviations, variances and means

	Population	Consumption
Mean	2 662 076 inhabitants	73 305 456,5 m^3/year
Standard deviation	4,8647.10^5	2,0318.10^7
Variance	2,366.10^{11}	4,128.10^{14}

Table 4 gives high values of the standard deviation, this means that the values are scattered around the mean (heterogeneous series).

So we can conclude that the values are widely distributed.

Also, if we replace α and β with their values, the linear fit 1 becomes:

$$Cons = 40Pop - 3.10^7 \qquad (2)$$

From this relationship, we have established a projection of consumption as a function of the population until the year 2025 (Table 5).

Table 5. Projection with degree 1 polynomial interpolation of drinking water consumption in Dakar as a function of the population from 2019 to 2025

Years	Population	Consumption in m3
Year 2019	3 732 284	116 032 102
Year 2020	3 835 019	120 133 663
Year 2021	3 938 358	124 259 338
Year 2022	4 042 225	128 406 093
Year 2023	4 146 593	132 572 850
Year 2024	4 251 430	136 758 331
Year 2025	4 356 697	144 267 880

3.2. Approximation by an Interpolation Polynomial of Degree 5.

Next, we have established the point clouds given by the interpolation polynomial of degree 5 in Figure 3.

Figure 3 shows how water consumption in Dakar has changed in relation to the population from 1997 to 2018 according to the polynomial interpolation of degree 5.
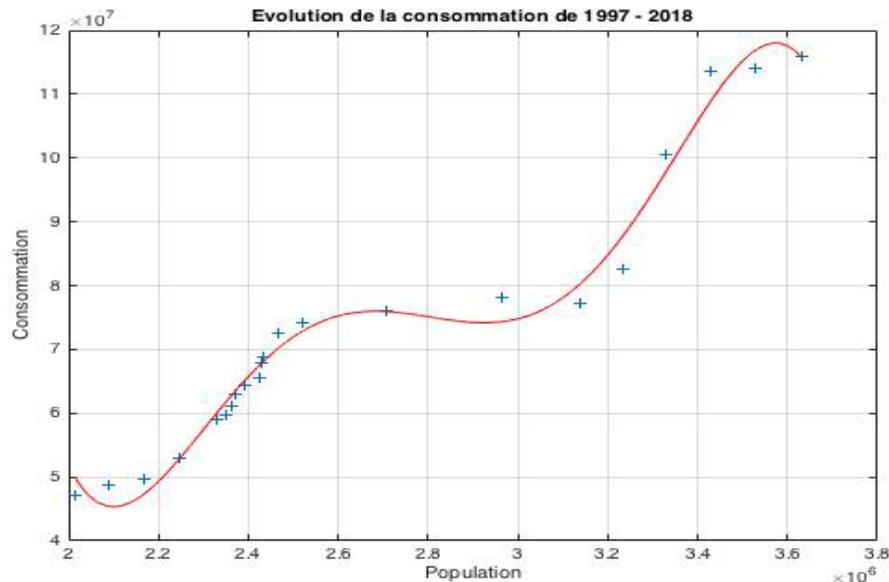

Figure 3. Curve of the consumption (m3) of drinking water compared to the population from 1997 to 2018 from the interpolation polynomial of degree 5

We used a polynomial interpolation of degree 5 which gives:

$$Cons = \alpha' \, Pop5 - \beta' \, Pop4 + \gamma' \, Pop3 + \theta' \, Pop2 + \delta' \, Pop + contante \; c' \quad (3)$$

We have the following values of α', β', γ', θ', δ' and c':

$$\alpha' = \beta' = \gamma' = 0$$
$$\theta' = 0,06196$$
$$\delta' = -8,4269.10^4$$
$$c' = 4,5308.10^{10}$$

Therefore, if we replace α', β', γ', θ', δ'and c with their values, the polynomial interpolation of degree 5 becomes:

$$Cons = 0,06196 Pop^2 - 8,4269.10^4 \, Pop + 4,5308.10^{10} \quad (4)$$

In addition, in 2005, the stoppage of drilling in Grand Medina due to a breakdown and those in Thiaroye due to public health problems (contamination of the water table) made production constant while demand increased. This explains the plateau at the level of the curve of the interpolation polynomial of degree 5.

Table 6. Projection with degree 5 polynomial interpolation of drinking water consumption in Dakar as a function of the population from 2019 to 2025

Years	Population	Consumption in m3
Year 2019	3 732 284	74 345 008
Year 2020	3 835 019	80 185 932
Year 2021	3 938 358	87 760 465
Year 2022	4 042 225	97 949 071
Year 2023	4 146 593	108 909 916
Year 2024	4 251 430	116 896 931
Year 2025	4 356 697	115 795 088

From equation 4, we have established Table 6 which gives a projection of drinking water consumption compared to the population from the year 2019 to the year 2025.

3.3. Approximation by an Interpolation Polynomial of Degree 10

Finally, we have established the point clouds given by the interpolation polynomial of degree 10 in Figure 4.

Thus, Figure 4 shows how water consumption in Dakar has evolved compared to the population from 1997 to 2018 according to the polynomial interpolation of degree 10.

Thus, the results of polynomial interpolation of degree 10 give:

$$\alpha''_{(10)} = \alpha''_{(9)} = \alpha''_{(8)} = \alpha''_{(7)}$$
$$= \alpha''_{(6)} = \alpha''_{(5)} = \alpha''_{(4)} = \alpha''_{(3)} = 0$$
$$\alpha''_{(2)} = 8,959.10^2$$
$$\alpha''_{(1)} = -5,2592.10^8$$
$$c'' = 1,382.10^{14}$$

Therefore, if we replace the coefficients with their values, the polynomial interpolation of degree 10 becomes:

$$Cons = 8,959.10^2 \, Pop^2 - 5,2592.10^8 \, Pop + 1,382.10^{14} \quad (5)$$

From this relationship, we have established Table 7 which gives a projection of drinking water consumption compared to the population from the year 2019 to the year 2025.
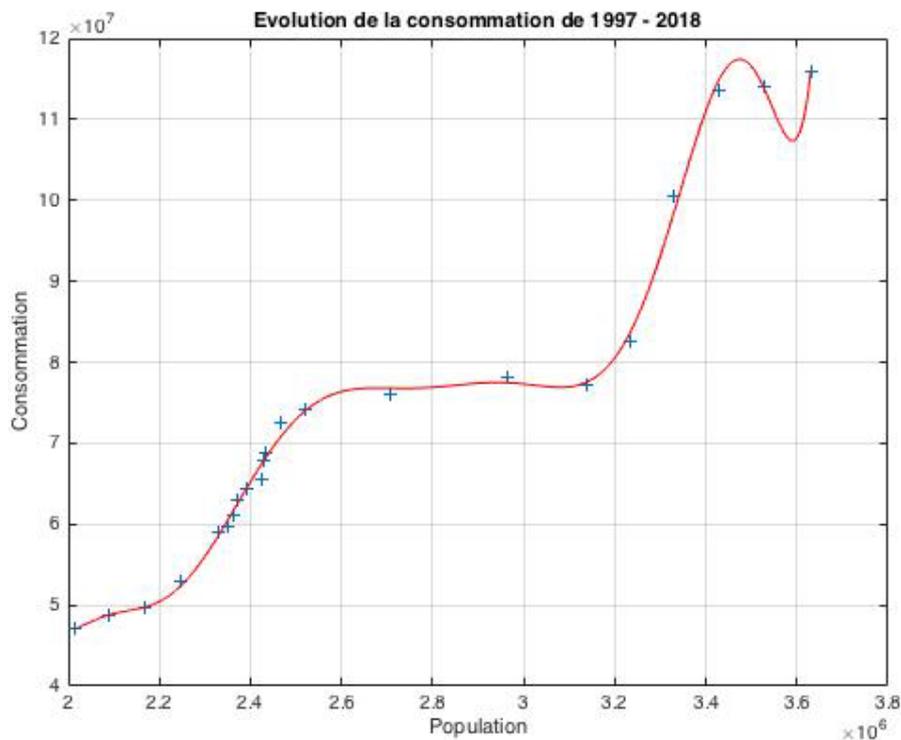
Figure 4. Curve of the consumption (m3) of drinking water compared to the population from 1997 to 2018 from the interpolation polynomial of degree 10

Table 7. Projection with polynomial interpolation of degree 10 of drinking water consumption in Dakar as a function of the population from 2019 to 2025

Years	Population	Consumption in m³
Year 2019	3 732 284	77 466 976
Year 2020	3 835 019	77 519 603
Year 2021	3 938 358	83 658 857
Year 2022	4 042 225	98 652 565
Year 2023	4 146 593	114 948 650
Year 2024	4 251 430	113 660 919
Year 2025	4 356 697	115 976 124

3.4. Interpretation of the Errors of the Different Interpolations

The results of the calculations of the different interpolations (degree 1, degree 5, degree 10) gave the margins of error for the different polynomials studied.

These margins of error are recorded in Table 8.

From Table 8, the trend curves of Figure 5 are established. These curves will make it possible to interpret the reliability of the polynomial interpolations but also to designate the optimal polynomial in order to establish a better projection of the evolution of drinking water consumption in the Dakar Region.

Table 8. The margins of error of the studied polynomials

Years	Margins of Error (m³/year) polynomial of degree 1	Margins of Error (m³/year) polynomial of degree 5	Margins of Error (m³/year) polynomial of degree 10
2019	7 312 668	3 750 175	628 207
2020	14 972 895	2 884 817	218 488
2021	13 600 675	5 243 914	1 142 305
2022	605 588	2 655 605	1 952 111
2023	9 709 838	4 738 602	1 300 131
2024	6 146 945	2 821 730	414 282
2025	3 961 717	128 137	52 898
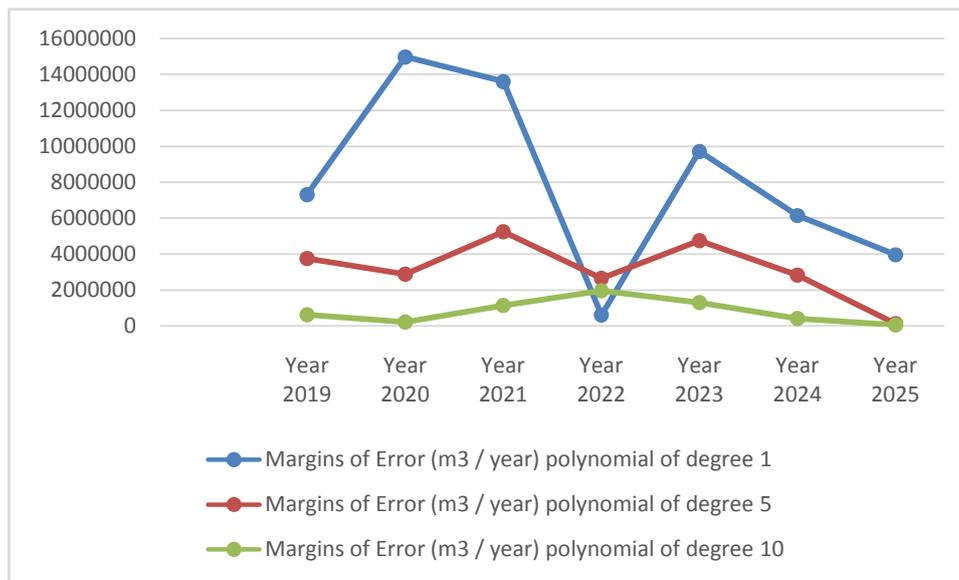
Figure 5. Trend curves of the margins of error of the different polynomials studied

Figure 5 shows that the polynomial of degree 10 has very small margins of error compared to other polynomials. For some years (2020, 2024 and 2025), the margins of error are even negligible.

Therefore, the best interpolation in order to have an optimal projection of the evolution of drinking water consumption as a function of the population is the polynomial of degree 10.

This polynomial of degree 10 is given by equation 5.

$$Cons = 8,959.10^2 \, Pop^2 - 5,2592.10^8 \, Pop + 1,382.10^{14}$$

4. Conclusion

We have tried several polynomial interpolations (degree 1, degree 5 and degree 10).

According to the results obtained, **the Dakar equation**, the best interpolation in order to have an optimal projection of the evolution of drinking water consumption as a function of the population, is given by the polynomial of degree 10.

This polynomial of degree 10 is given by the following equation 5:

$$Cons = 8,959.10^2 \, Pop^2 - 5,2592.10^8 \, Pop + 1,382.10^{14}$$

In addition, the infrastructures built constitute, by their number and their very varied functions, not only a real attraction, but also a demographic amplifier.

In fact, special attention must be paid to the assessment of available drinking water resources in relation to future needs.

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