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Calibration of Water Distribution Network Models and Comparison between (DDA) and (PDA)

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Abstract

In this study, we present a calibration methodology for drinking water distribution network models using two hydraulic simulation approaches: Demand Driven Analysis (DDA) and Pressure Driven Analysis (PDA), implemented in EPANET 2.2. The calibration process focuses on determining two critical parameters the discharge coefficient and the pressure exponent which govern flow behavior under pressure-dependent conditions. Unlike DDA, which assumes fixed consumption at nodes regardless of pressure, PDA accounts for variable flow rates based on available pressure, offering a more realistic representation of network performance during low-pressure scenarios. These coefficients were derived from national plumbing standards applicable to different consumer categories in Algeria and Romania, and integrated into the numerical models to enhance simulation accuracy. A detailed comparison between DDA and PDA is provided, highlighting the strengths and limitations of each approach. Importantly, this type of numerical model is especially valuable during the design phase of water distribution systems, when physical measurements are unavailable and planning decisions must rely on regulatory data and theoretical assumptions.

Keywords

Water Distribution System, Calibration, Simulation, Demand Driven Analysis, Pressure Driven Analysis

1. Introduction

The primary objective of any water distribution system is to deliver the required quantity of water to consumers at adequate pressure and in accordance with established quality standards. To achieve this, it is essential to develop mathematical models that accurately simulate the behavior of the network under various operating conditions. Such models are indispensable tools for water utilities, engineers, and planners involved in the design, operation, and maintenance of distribution systems [1].

Hydraulic simulation models have become standard practice in the analysis of water networks [2], enabling users to evaluate system performance, identify weaknesses, and optimize infrastructure. However, for these models to be reliable, they must be calibrated using appropriate parameters that reflect real-world conditions. Calibration involves determining key coefficients such as the discharge coefficient and pressure exponent that influence flow behavior, particularly under pressure-dependent scenarios.

EPANET, developed by the United States Environmental Protection Agency, has long been a widely used tool for simulating water distribution systems [3]. Earlier versions relied solely on Demand Driven Analysis (DDA), which assumes that consumer demand is always fully met, regardless of the pressure available at each node. While this approach simplifies modeling, it fails to capture the realities of low-pressure conditions, such as those occurring during peak demand, emergencies, or system failures.

To address these limitations, EPANET 2.2 introduced Pressure Driven Analysis (PDA), which adjusts flow rates based on available pressure, offering a more realistic simulation of network behavior [4]. This study utilizes both DDA and PDA approaches to calibrate water distribution models for two networks N'gaous in Algeria and Lacul Tei in Romania each representing different distribution systems (gravity-fed and pumped, respectively).

2. Numerical Method

To simulate the behavior of a water distribution network using a pressure-based approach, researchers used the emitter approach to model partial flow conditions. An emitter is used to represent pressure-dependent distribution demand. EPANET introduced a special element called an emitter in its hydraulic simulation engine [5]. The emitter behaves like a sprinkler that delivers flow to a node in proportion to the head available at that node, and it determines the actual supply at demand nodes based on the available pressure.

The emitter equation in EPANET is expressed as shown in Equation (1)

$$q = C \cdot P^{\gamma} \tag{1}$$

where q: is the flow rate of orifice at demand node, C: discharge coefficient, P is the pressure at demand node. [4] γ is the power of pressure (pressure exponent) (γ is equal to 0.5 that is the default value in EPANET software.) for distribution flow through fixed area orifices but may vary in a range of 0.5 - 2.5 for real water networks [6], and also 0.5 - 2.79 [7]. In this paper, we will find the two parameters (discharge coefficient and pressure exponent) because the Algorithms based on pressure do not consider the consumption flows at fixed nodes but variable depending on the available pressure in the restrictive node.

However, the law of variation of the consumption flow depending on the pressure must be specified by correctly determining these coefficients starting from the norms in force for different categories of consumers.

3. Coefficients Determination

1) Estimation of the probable flow rates according to the number of apartments and floors

In this part of the work, we presented the flow rate requirement of each apartment following the standard equipment it contains based on the standards in force; for the case of Algeria we have the French standards [8] with some adjustments and for the case of Romania we applied the Romanian standards [9]. The work in general affects the cases of 01 up to 10 dwellings per floor on a maximum height of 10 floors and the calculation method for the rest of the cases is similar. Based on our survey and knowledge of the housing model in the study areas of these two countries (Algeria and Romania), we took several cases in which we assumed that there were the largest possible number of apartments on each floor and that they were very high, that is, the building or building is wide and contains several apartments (6 to 7 apartments) on each floor and is very high (Ground floor + 10 floors), as is the case in Romania and Algeria in general, the building is composed of (2 to 4 apartments) on each floor and is high (Ground floor + 4 floors).

2) Estimate the basic flow according to the standards contained in the documents of each country

3) Calculation of the probable flow rate which represents the maximum flow rate that can exist in a section of pipeline, according to the following formula:

$$q_p = \sum q_b \cdot K \quad (2)$$

4) Calculation of the coefficient of simultaneity according to the number of devices installed, according to the formula of (NF DTU 60.11 P1-1) [10]

$$K = \frac{0.8}{\sqrt{x-1}} \quad (3)$$

In the case of Romania, we applied the same methodology to organize the procedures; the only difference is in the way of calculating the basic flow rates because Romania has its own standards and method different from (NF DTU 60.11 P1-1). Among these differences, there is the one according to the wording of the Romanian standards (No. 1167 bis/6.XII.2022).

- The coefficient of simultaneity is calculated with the following formula because there are two types of coefficient of simultaneity: the coefficient of simultaneity for hot water and the coefficient of simultaneity for cold water, which is calculated with the following formula:

$$f_{AR} = \frac{0.83}{\sqrt{N-1}} \quad (4)$$

- The B-2 method was adopted because the consumption unit, U_i for a reinforcement $U \geq 15$. [9]

Therefore, the following calculation flow rate relations apply:

$$Q_{C,AR} = Q_{S,tot,AR} \times f_{AR} \quad (5)$$

Limitations of Plumbing Norms

Although national plumbing standards offer a valuable baseline for estimating emitter coefficients, they may not fully capture real-world complexities such as leaks, unmetered consumption, or behavioral variations. Therefore, while these coefficients serve as a solid foundation for calibration, future research should explore hybrid approaches combining normative data with field measurements for greater precision.

4. Case Study

Estimation of probable flow rates depending on the number of housing units and floors.

In this part of the work, we presented the flow requirements for each dwelling according to the standard documents it contains, based on current standards. For Algeria, we used the French DTU60 standards with some adjustments, and for Romania, we applied the Romanian standards according to the Official Journal of Romania, Part I, N˚. 1167 bis/6.XII.2022 (monitorul oficial al româniei, partea I, Nr. 1167 bis/6.XII.2022). The work generally covers cases of 1 to 10 dwellings per floor with a maximum height of 10 floors.

In this article, we present the procedure followed in the case of 04 apartments per floor for the city of N'gaous in Algeria and 07 apartments per floor for the city of Lacul Tei, Romania, and the calculation method for the rest of the cases is similar, as shown in Table 1 and Table 2.

Table 1. Estimated probable flow rates for the case of (04) apartment/floor on 10 Floor (Case of Algeria).

Floor		**Gf**	**F-1**	**F-2**	**F-3**	**F-4**	**F-5**	**F-6**	**F-7**	**F-8**	**F-9**	**F-10**
Designation		Pressure demand per floor in (m)										
		5	**8**	**11**	**14**	**17**	**20**	**23**	**26**	**29**	**32**	**35**
Device Type/Apartment	Flow **(ℓ/s)**	Basic flow of devices according to the type and number of apartments in (ℓ/s)										
Sink	0.2	0.8	1.6	2.4	3.2	4	4.8	5.6	6.4	7.2	8	8.8
Wash basin	0.2	0.8	1.6	2.4	3.2	4	4.8	5.6	6.4	7.2	8	8.8
Shower	0.2	0.8	1.6	2.4	3.2	4	4.8	5.6	6.4	7.2	8	8.8
Bathtub	0.33	1.32	2.64	3.96	5.28	6.6	7.92	9.24	10.56	11.88	13.2	14.52
Basin hand wash	0.1	0.4	0.8	1.2	1.6	2	2.4	2.8	3.2	3.6	4	4.4
Washing machine	0.2	0.8	1.6	2.4	3.2	4	4.8	5.6	6.4	7.2	8	8.8
WC with flush tank	0.12	0.48	0.96	1.44	1.92	2.4	2.88	3.36	3.84	4.32	4.8	5.28
Total	1.35	5.4	10.8	16.2	21.6	27	32.4	37.8	43.2	48.6	54	59.4

Continued

Number of apartments	4	8	12	16	20	24	28	32	36	40	44
Number of devices	28	56	84	112	140	168	196	224	252	280	308
Coefficient of simultaneity	0.154	0.108	0.088	0.076	0.068	0.062	0.057	0.054	0.050	0.048	0.046
Q probable in (ℓ/s)	0.831	1.165	1.423	1.640	1.832	2.006	2.166	2.314	2.454	2.586	2.712

Table 2. Estimated probable flow rates for the case of (07) apartment/floor on 10 Floor (Case of Romania).

Floor			**Gf**	**F-1**	**F-2**	**F-3**	**F-4**	**F-5**	**F-6**	**F-7**	**F-8**	**F-9**	**F-10**
Designation			Pressure demand per floor in (m)										
			5	**8**	**11**	**14**	**17**	**20**	**23**	**26**	**29**	**32**	**35**
Device Type/Apartment	Flow (ℓ/s)	Unit (Ui)	Basic flow rate of devices according to the type and number of dwellings ($Q_{s,\ tot}$) in (ℓ/s)										
Sink	0.2	2	1.4	2.8	4.2	5.6	7	8.4	9.8	11.2	12.6	14	15.4
Wash basin	0.15	1.5	1.05	2.1	3.15	4.2	5.25	6.3	7.35	8.4	9.45	10.5	11.55
Shower	0.2	2	1.4	2.8	4.2	5.6	7	8.4	9.8	11.2	12.6	14	15.4
Bathtub	0.25	3	1.75	3.5	5.25	7	8.75	10.5	12.25	14	15.75	17.5	19.25
Toilet sink	0.1	1	0.7	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	7	7.7
WC with wash tank	0.12	1	0.84	1.68	2.52	3.36	4.2	5.04	5.88	6.72	7.56	8.4	9.24
Washing machine	0. 2	2	1.4	2.8	4.2	5.6	7	8.4	9.8	11.2	12.6	14	15.4
Dishwasher machine	0.2	2	1.4	2.8	4.2	5.6	7	8.4	9.8	11.2	12.6	14	15.4
Total	1.42	14.5	9.94	19.88	29.82	39.76	49.7	59.64	69.58	79.52	89.46	99.4	109.34
Number of apartments			7	14	21	28	35	42	49	56	63	70	77
Number of devices/Apartment			56	112	168	224	280	336	392	448	504	560	616
Coefficient of simultaneity			0.112	0.079	0.064	0.056	0.050	0.045	0.042	0.039	0.037	0.035	0.033
Q probable in (ℓ/s)			1.112	1.566	1.915	2.210	2.470	2.705	2.921	3.122	3.311	3.489	3.659

4.1. Case of Algeria

In this case, we present the procedure for the case of 4 apartments/floor on 10 floors, as shown in Table 1.

The flow-pressure curve is plotted to represent the relationship between the flow (q) supplied by an emitter (such as a dripper, faucet, or pump) and the pressure (P) available at its inlet.

This curve has several functions, which are:

- Visualize the sensitivity of flow rate to pressure variations which allows us to see how the flow rate changes when the pressure increases or decreases. This helps us understand the hydraulic behavior of a system.
- The main and important point is to determine the coefficients of the equation: $q = C \cdot P^{\gamma}$, which is: discharge coefficient "C" and pressure exponent "γ", as shown in Figure 1 and Figure 2 for the cases of Algeria and Romania.

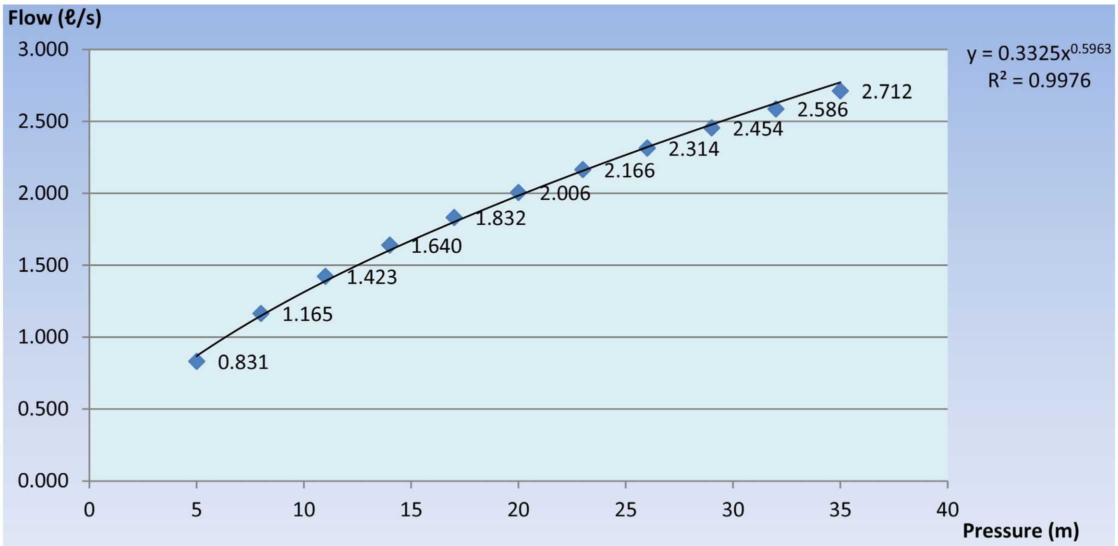

Figure 1. Graphical representation of the probable flow variation (q_P) as a function of the requested pressure (Case of Algeria).

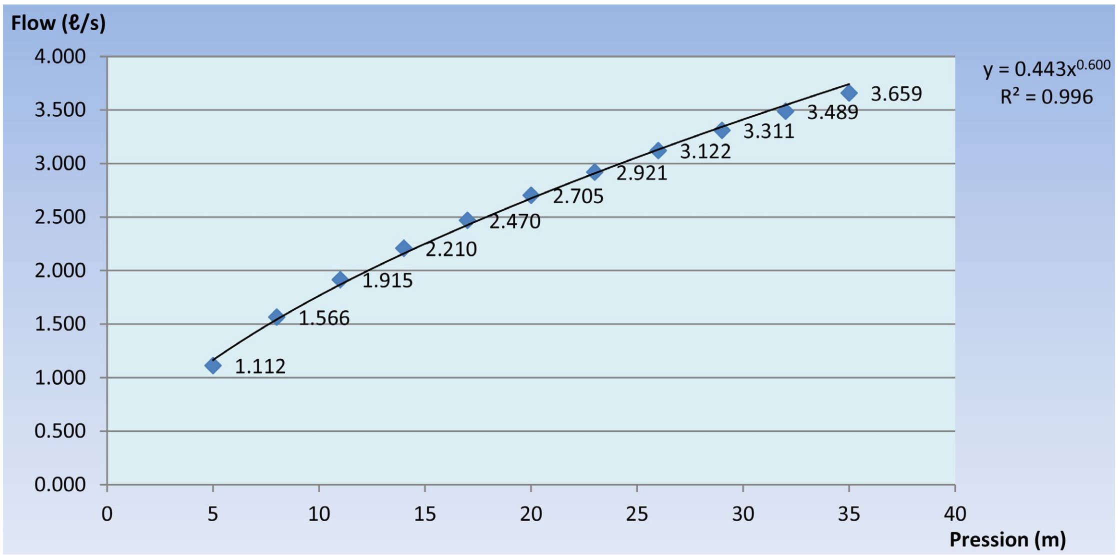

Figure 2. Graphical representation of the probable flow variation (q_P) as a function of the requested pressure (Case of Romania).

4.2. Case of Romania

In this case, we present the procedure for the case of 7 apartments/floor on 10 floors, as shown in Table 2.

5. Result and Discussion

In the context of searching for the discharge coefficient (C) and the pressure coefficient (γ) related to the emitter Formula (1).

After conducting a study on two cases, namely Algeria and Romania, the initial results obtained through the following two Table 3 and Table 7 were:

Table 3. The coefficients adopted "Case initial" (Case of Algeria).

Designation	Form of the equation	Coefficients	
	$q = c \cdot p^{\gamma}$	c	γ
1 apartment/floor on 10 floors	$q = 0.180p^{0.572}$	0.180	0.572
2 apartment/floor on 10 floors	$q = 0.241p^{0.588}$	0.241	0.588
3 apartment/floor on 10 floors	$q = 0.290p^{0.593}$	0.290	0.593
4 apartment/floor on 10 floors	$q = 0.332p^{0.596}$	0.332	0.596
5 apartment/floor on 10 floors	$q = 0.369p^{0.957}$	0.369	0.957
6 apartment/floor on 10 floors	$q = 0.403p^{0.598}$	0.403	0.598
7 apartment/floor on 10 floors	$q = 0.435p^{0.599}$	0.435	0.599
8 apartment/floor on 10 floors	$q = 0.464p^{0.600}$	0.464	0.600
9 apartment/floor on 10 floors	$q = 0.491p^{0.600}$	0.491	0.600
10 apartment/floor on 10 floors	$q = 0.517p^{0.600}$	0.517	0.600

5.1. Case of Algeria

Observation and Interpretation

1) *Observation*

We note for this case for Algeria that the pressure exponent (γ) is defined in the equation: $q = cp^{\gamma}$.

Often takes values very close to 0.600 and it varies according to the table above (**Table 3**) from 0.572 to 0.600.

We consider that, as a first approach, the pressure exponent (γ) most appropriate for our case will have a value of 0.600 and we will gradually correct the values of our **Table 4** according to this value, which is also graphically represented in **Figure 3**.

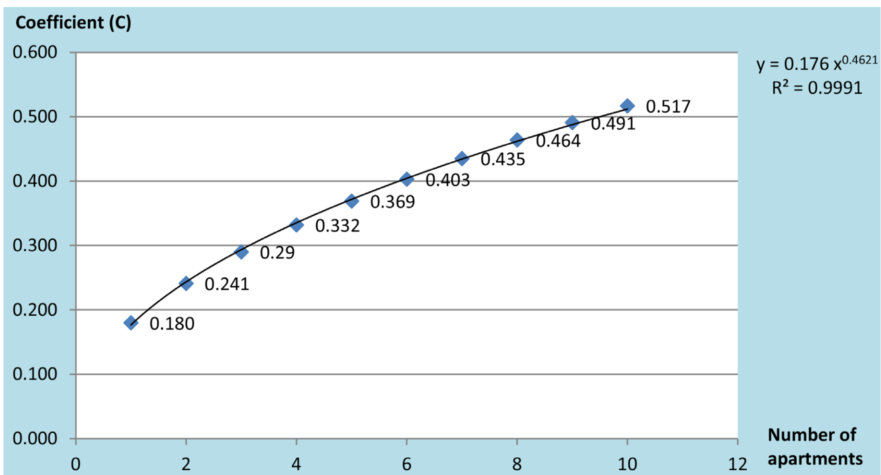

Figure 3. Graphical representation of the variation of coefficient (C) as a function of the number of dwellings per floor.

Table 4. Variation of coefficient (*a*) according to the number of dwellings per floor.

Number of Apartments	1	2	3	4	5	6	7	8	9	10
Coefficient (C)	0.180	0.241	0.290	0.332	0.369	0.403	0.435	0.464	0.491	0.517

Based on the values in Table 4, we plotted the curve in Figure 3 to graphically illustrate the variation of coefficient (C) as a function of the number of residential units per floor, and to deduce an analytical relationship between these two coefficients.

2) ***Interpretation***

By observing the values of the coefficient C obtained by the graphs relating to each calculation case which is presented by the number of housing/floor up to 10 maximum floors, we were able to observe that the value of the coefficient C increases as the number of housing per floor increases, which is why we decided to represent the cloud of points obtained by the values of the variation table of the coefficient C to have the form of the equation which manages the variation of this coefficient according to the number of housing per floor (Figure 3).

We obtained the curve above which has the equation: $y = 0.176x^{0.462}$.

We note that this equation does not give the value of 0.180 for $x = 1$, which is why to adopt this equation as a general formula for calculating the probable flow rate in a general manner it is necessary to test this formula and make a comparison for all the values of the coefficient C in the summary table by making a comparison between the values of the coefficient C obtained by direct calculation and by the equation: $y = 0.180x^{0.462}$.

This gives the exact value of C for $x = 1$, which translates to the results in Table 5:

Table 5. Comparison of coefficient values (C).

Number of apartments		1	2	3	4	5	6	7	8	9	10
Coefficient (c)	$y = 0.176x^{0.462}$	0.176	0.242	0.292	0.334	0.370	0.403	0.432	0.460	0.486	0.510
Coefficient (c)	$y = 0.180x^{0.462}$	0.180	0.248	0.299	0.342	0.379	0.412	0.442	0.470	0.497	0.522
Coefficient (c) by direct calculation see Table 4		0.180	0.241	0.29	0.332	0.369	0.403	0.435	0.464	0.491	0.517

Analyzing the results of Table 5 above we notice that the values of C closest to the values obtained by direct calculation are those obtained by the equation: $y = 0.176x^{0.462}$.

Plotting the curve of the values of C obtained by the equation: $y = 0.176x^{0.462}$.

We get the curve below (Figure 4) which is almost identical to the graph representing the point cloud of the function: $C = f(N)$ shown in Figure 3.

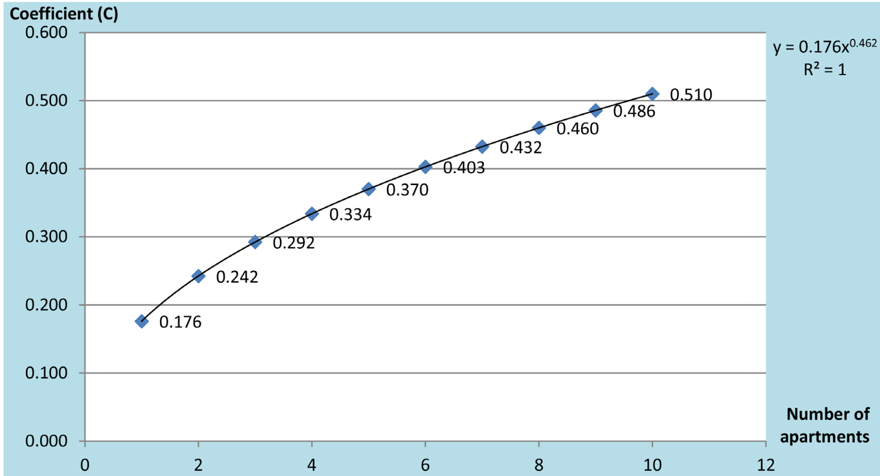

Figure 4. Curve of the variation of the coefficient C as a function of the number of dwellings per floor curve of the equation: $y = 0.176x^{0.462}$.

We will adopt this equation for the calculation of the different coefficients C relative to each case.

Consequently, we will take the values of the coefficient C and γ of (**Table 6**) below as a reference for our future calculations.

Table 6. The coefficients adopted "final case" (Case of Algeria).

Designation	Form of the equation	Coefficients	
	$q = c \cdot p^{\gamma}$	c	γ
1 apartment/floor on 10 floors	$q = 0.176p^{0.6}$	0.176	0.6
2 apartment/floor on 10 floors	$q = 0.242p^{0.6}$	0.242	0.6
3 apartment/floor on 10 floors	$q = 0.292p^{0.6}$	0.292	0.6
4 apartment/floor on 10 floors	$q = 0.334p^{0.6}$	0.334	0.6
5 apartment/floor on 10 floors	$q = 0.370p^{0.6}$	0.370	0.6
6 apartment/floor on 10 floors	$q = 0.403p^{0.6}$	0.403	0.6
7 apartment/floor on 10 floors	$q = 0.432p^{0.6}$	0.432	0.6
8 apartment/floor on 10 floors	$q = 0.460p^{0.6}$	0.460	0.6
9 apartment/floor on 10 floors	$q = 0.486p^{0.6}$	0.486	0.6
10 apartment/floor on 10 floors	$q = 0.510p^{0.6}$	0.510	0.6

5.2. Case of Romania

The same applies to the case of Romania, where in the context of searching for the discharge coefficient (C) and the pressure coefficient (γ) related to the emitter Formula (1). The initial results obtained through the following (**Table 7**) were:

Table 7. The coefficients adopted "case initial" (Case of Romania).

Designation	Form of the equation	Coefficients	
	$q = c \cdot p^{\gamma}$	c	γ
1 apartment/floor on 10 floors	$q = 0.181p^{0.582}$	0.181	0.582
2 apartment/floor on 10 floors	$q = 0.244p^{0.595}$	0.244	0.595
3 apartment/floor on 10 floors	$q = 0.295p^{0.597}$	0.295	0.597
4 apartment/floor on 10 floors	$q = 0.338p^{0.599}$	0.338	0.599
5 apartment/floor on 10 floors	$q = 0.376p^{0.600}$	0.376	0.600
6 apartment/floor on 10 floors	$q = 0.411p^{0.600}$	0.411	0.600
7 apartment/floor on 10 floors	$q = 0.443p^{0.600}$	0.443	0.600
8 apartment/floor on 10 floors	$q = 0.473p^{0.600}$	0.473	0.600
9 apartment/floor on 10 floors	$q = 0.501p^{0.600}$	0.501	0.600
10 apartment/floor on 10floors	$q = 0.527p^{0.601}$	0.527	0.601

Observation and Interpretation

1) ***Observation***

We note for the case of Romania that the pressure exponent (γ) defined in the equation: $q = c \cdot p^{\gamma}$.

Often takes the value of 0.600 and it varies according to the table above (Table 7) from 0.582 to 0.601.

We consider, as a first approach, that the pressure exponent (γ) most suitable for us will have a value of 0.600 and we will gradually correct the values of our Table 7 and Table 8 according to this value.

Table 8. Variation of the coefficient (C) according to the number of dwellings per floor.

Number of apartments	1	2	3	4	5	6	7	8	9	10
Coefficient C	0.181	0.244	0.295	0.338	0.376	0.411	0.443	0.473	0.501	0.527

Based on the values in Table 8, we plotted the curve in Figure 5 to graphically illustrate the variation of coefficient (C) as a function of the number of residential units per floor, and to deduce an analytical relationship between these two coefficients.

2) ***Interpretation***

By observing the values of the coefficient C obtained by the graphs relating to each calculation case that is presented by the number of apartments/floor up to 10 maximum floors, we were able to observe that the value of the coefficient C increases as the number of housing per floor increases, which is why we decided to represent the cloud of points obtained by the values of the variation table of the coefficient C to have the form of the equation that manages the variation of this coefficient according to the number of apartments per floor. We obtained the curve (Figure 5) which has the equation: $y = 0.178x^{0.467}$.

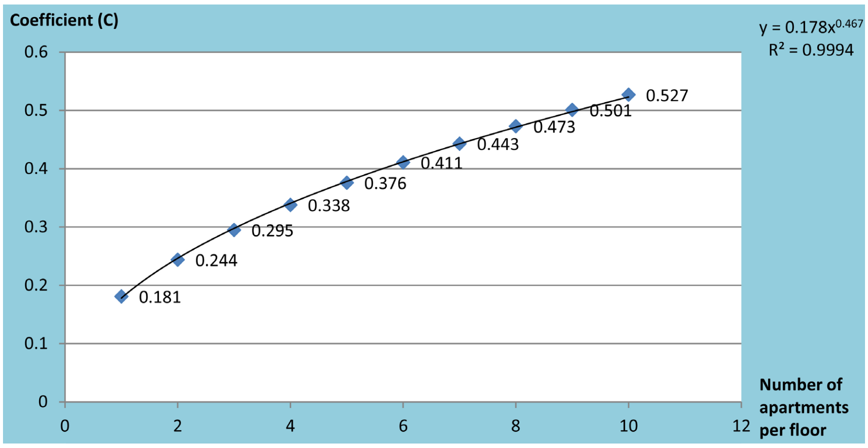

Figure 5. Graphical representation of the variation of the coefficient C as a function of the number of apartments per floor.

We note that this equation does not give the value of 0.181 for $x = 1$, which is why to adopt this equation as a general formula for calculating the probability flow in a general manner, it is necessary to test this formula and make a comparison for all the values of the coefficient C in the summary table by making a comparison between the values of the coefficient C obtained by direct calculation and by the equation: $y = 0.181x^{0.467}$.

Which gives the exact value of C for $x = 1$.

These results are shown in the following Table 9:

Table 9. Comparison of coefficient values C.

Number of apartments		1	2	3	4	5	6	7	8	9	10
Coefficient C	$y = 0.181x^{0.467}$	0.181	0.250	0.302	0.346	0.384	0.418	0.449	0.478	0.505	0.530
	$y = 0.178x^{0.468}$	0.178	0.246	0.297	0.340	0.377	0.411	0.442	0.470	0.497	0.522
Coefficient C by direct calculation see Table 8		0.181	0.244	0.295	0.338	0.376	0.411	0.443	0.473	0.501	0.527

Analyzing the results of the table above (Table 9), we notice that the values of C closest to the values obtained by direct calculation are those obtained by the equation: $y = 0.181x^{0.467}$.

By tracing the curve of the values of C obtained by the equation: $y = 0.181x^{0.467}$.

We obtain the curve below (Figure 6) which is almost identical to the curve (Figure 5) representing the point cloud of the function: $C = f(N)$.

- Graphical representation of the variation of the coefficient C according to the number of apartments per floor is shown in Figure 6.

We will adopt this equation for the calculation of the different coefficients C relative to each case.

Consequently, we will take the values of the coefficient C and y from the table below (Table 10) as a reference for our future calculations.

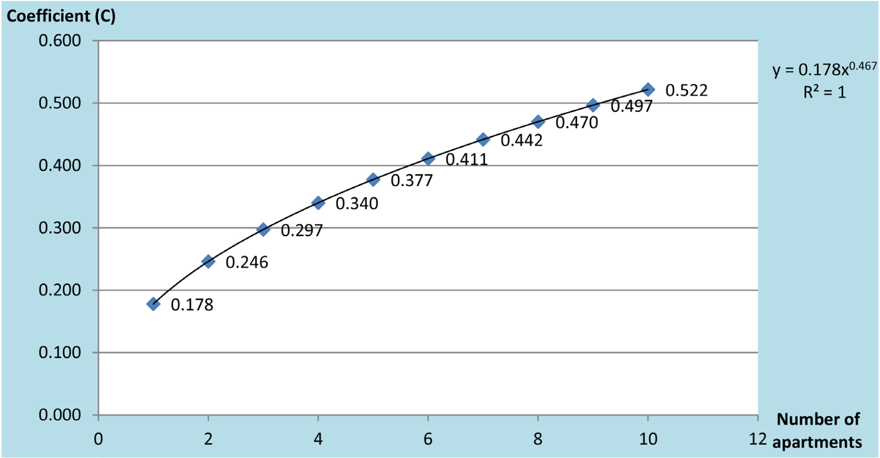

Figure 6. Curve of the variation of the coefficient (C) as a function of the number of apartments per floor curve of the equation: $y = 0.178x^{0.467}$.

Table 10. The coefficients adopted "final case" (Case of Romania).

Designation	Form of the equation	Coefficients	
	$q = c \cdot p^{\gamma}$	c	γ
1 apartment/floor on 10 floors	$q = 0.178p^{0.6}$	0.178	0.6
2 apartment/floor on 10 floors	$q = 0.246p^{0.6}$	0. 246	0.6
3 apartment/floor on 10 floors	$q = 0.297p^{0.6}$	0.297	0.6
4 apartment/floor on 10 floors	$q = 0.340p^{0.6}$	0.340	0.6
5 apartment/floor on 10 floors	$q = 0.377p^{0.6}$	0.377	0.6
6 apartment/floor on 10 floors	$q = 0.411p^{0.6}$	0.411	0.6
7 apartment/floor on 10 floors	$q = 0.442p^{0.6}$	0.442	0.6
8 apartment/floor on 10 floors	$q = 0.470p^{0.6}$	0.470	0.6
9 apartment/floor on 10 floors	$q = 0.497p^{0.6}$	0.497	0.6
10 apartment/floor on 10floors	$q = 0.522p^{0.6}$	0.522	0.6

1) Justification of $\gamma = 0.6$ and Sensitivity Analysis

The selection of $\gamma = 0.6$ is based on convergence of values observed across both case studies and supported by prior research indicating typical values between 0.5 and 0.6 for orifice-type flows. To assess the influence of γ, a sensitivity analysis was performed for a typical node with varying γ values (0.5, 0.6, 0.7). The results showed moderate sensitivity to γ, particularly at lower pressures, reinforcing the importance of accurate estimation.

2) Generalizability of Empirical Formulas

While the derived empirical relationships between the discharge coefficient (C) and the number of apartments per floor provide useful insights, their applicability is limited to the tested cases. These formulas are not universally generalizable without local calibration. Broader validation using different building typologies, climate zones, and consumer behaviors is needed to confirm the robustness of these coefficients.

5.3. Regression Performance

To evaluate the reliability of the fitted empirical formulas for discharge coefficient (C), we calculated the coefficient of determination (R^2) for both countries. The results indicate high goodness-of-fit, as shown below:

Country	Equation	R^2 (C vs. Number of Apartments)
Algeria	$q = 0.334 \cdot p^{0.6}$	($R^2 = 0.99$, RMSE = 0.012)
Romania	$q = 0.443 \cdot p^{0.6}$	($R^2 = 0.97$, RMSE = 0.015)

These high R^2 values confirm that the regression models accurately capture the relationship between C and building occupancy levels.

6. The Limitations of Deriving Emitter Coefficients Solely from Indoor Plumbing Norms, Especially regarding Leakage and Unmetered Uses

One of the limitations of this study is the derivation of emitter coefficients solely from national indoor plumbing norms. While these norms provide a sound basis for estimating theoretical consumption, they may not fully account for leakage, unauthorized consumption, and seasonal or behavioral variations. In practice, unmetered uses and aging infrastructure can lead to significant deviations from normative estimates. Thus, complementing these coefficients with field measurements or utility billing data would enhance model realism.

7. Hydraulic Simulation and Analysis Methods

There are two approaches that we normally use to run Hydraulic Modeling in EPANET, Demand Driven Analysis (DDA) and Pressure Driven Analysis (PDA).

This model-based Distribution localization methodology has been tested in the city of N'gaous in Algeria under a real Distribution scenario. This water network supplies the entire urban area of this city, covering around 33,619 inhabitants, and is managed by the Algerian Water Company. The whole water network is composed by 133,081 m of pipes, 03 boreholes to pump water to the tanks, and 03 reservoirs with a capacity of (1000 m^3) and 01 with a capacity of (150 m^3), 01 with a capacity of (500 m^3), located at the head of the networks and which serve as storage for the city. This network is segmented into 30 distribution areas. This network contains 417 nodes and 448 pipes. In **Figure 7** and **Figure 8**, the water network of the N'gaous city distribution area can be seen from the EPANET file, which contains the hydraulic model of this network. The same applies to the distribution network model for the city of Lacul Tei, in Bucharest, Romania.

The WDS numerical model in EPANET consists of 250 pipes and 212 nodes. The water pumping station uses variable-speed pumps and is operated by the Bucharest Water Company (**Figure 8** and **Figure 9**).

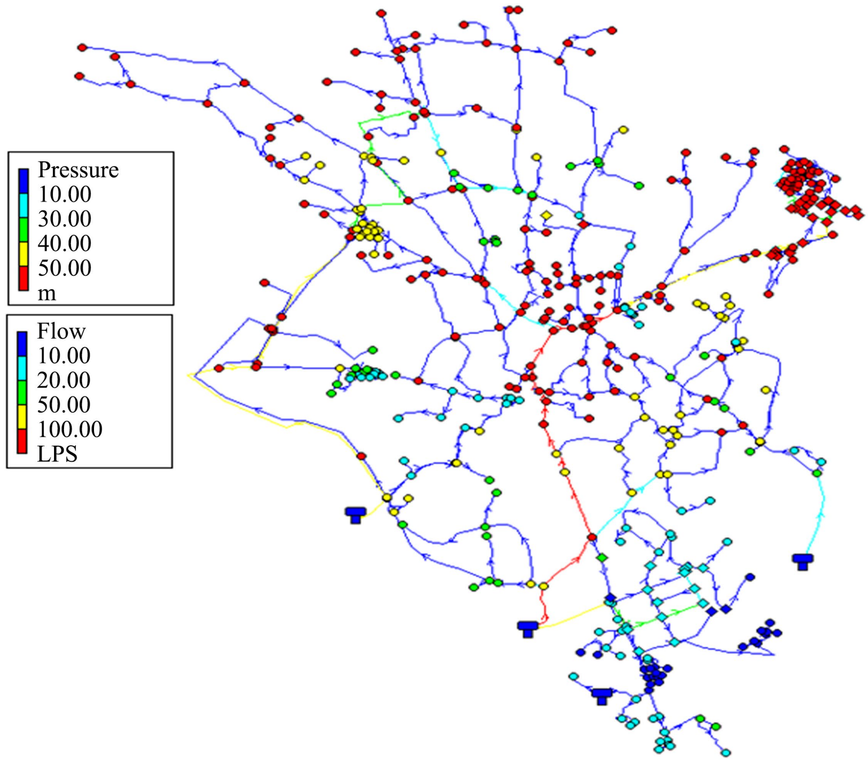

Figure 7. Water distribution network of the city N'gaous, simulation: Pressure-flow (DDA case).

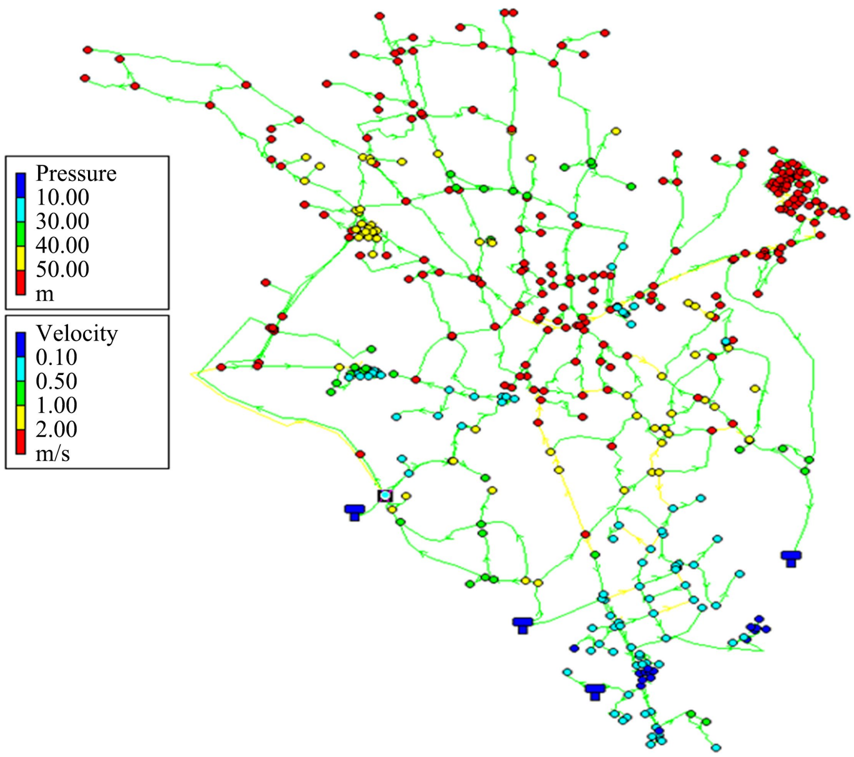

Figure 8. Water distribution network of the city N'gaous, simulation: Pressure-velocity (DDA case).

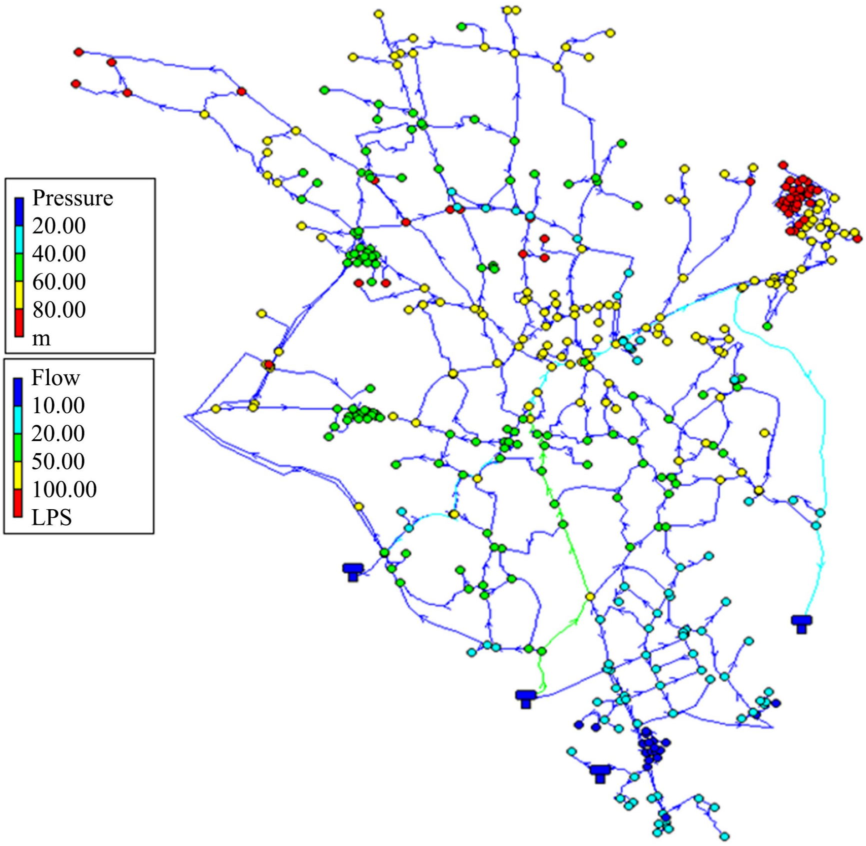

Figure 9. Water distribution network of the city N'gaous, simulation: Pressure-flow (PDA case).

In these figures, the simulation process was carried out for two cases: Demand Driven Analysis (DDA) and Pressure Driven Analysis (PDA) after inserting the previously defined parameters in the numerical model for the (PDA case) at nodes corresponding to the building type they supply.

To the best of our knowledge, the cases for these two cities are N'gaous in Algeria, with a (G + 4 floor) with 4 apartments on each floor building type, and Lacul Tei in Romania, with an (G + 10 floor) with 7 apartments on each floor.

Therefore, the coefficients entered into the numerical models for each city are as follows:

- For the city of N'gaous in Algeria, based on the equation obtained from Table 6).

Designation	Form of the equation	Coefficients	
	$q = c \cdot p^{\gamma}$	c	γ
4 apartment/floor on 10 floors	$q = 0.334p^{0.6}$	0.334	0.6

- For the city of Lacul Tei, in Bucharest-Romania, based on the equation obtained from Table 10.

Designation	Form of the equation	Coefficients	
	$q = c \cdot p^{\gamma}$	c	γ
7 apartment/floor on 10 floors	$q = 0.442p^{0.6}$	0.442	0.6

- Then the simulation process.

1st case: Demand Driven Analysis (DDA)

2nd case: Pressure Driven Analysis (PDA)

1st case: Demand Driven Analysis (DDA)

2nd case: Pressure Driven Analysis (PDA)

Regarding whether any measured pressures or flows were used to verify the calibrated models and derived coefficients.

No direct field measurements of pressure or flow rates were available for model validation. However, the calibration process was grounded on well-established plumbing norms (NF DTU 60.11 P1-1 and Romanian standard: Monitorul Oficial al româniei, partea I, Nr. 1167 bis/6.XII.2022) and carefully modeled flow requirements based on real household configurations. The coefficients were tested against expected behaviors under both DDA and PDA simulations, and the outputs aligned with operational expectations. Future studies may include field measurements to validate and enhance the robustness of the proposed empirical models.

8. Result and Discussion

Through these special models of the study areas, we note the following:

We applied the simulation to two drinking water distribution network models in two cities in two different countries. These two models differ in terms of the water distribution system: the first model uses a gravity distribution system, and the second uses a pumped distribution system.

There are main parameters for comparison.

8.1. Flows

- Flow rates at different points in the network are essential parameters for comparing the two approaches. DDA considers them as fixed, while PDA calculates them based on pressures.
- DDA provides a more detailed representation or assessment of consumption flows in the various network pipes, making it possible to identify areas potentially subject to capacity problems, while PDA analysis may underestimate these flows by not taking losses into account.

8.2. Pressure

- For the gravity distribution system (Figures 7-10) in both the DDA and PDA cases, the pressure depends on the position and location of the reservoir, *i.e.*, the reservoir has a higher point (elevated) than all the buildings in the city, thus ensuring good pressure and thus reducing energy costs.

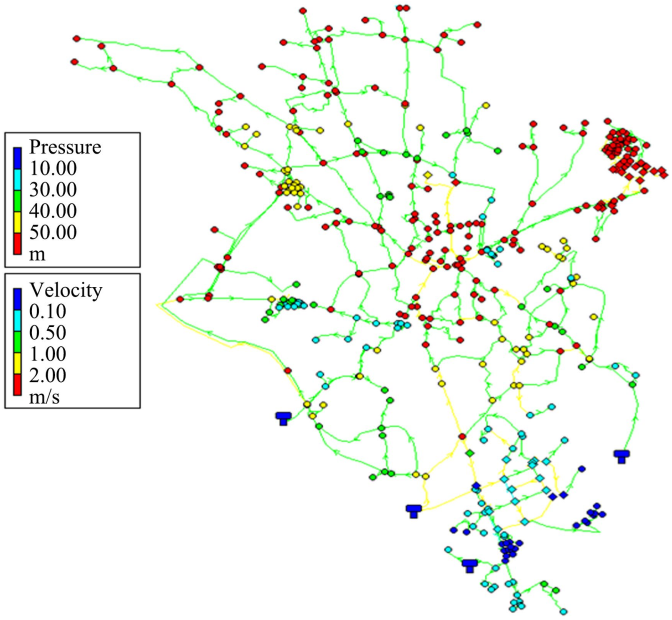

Figure 10. Water distribution network of the city N'gaous, simulation: Pressure-velocity (PDA case).

- For the pumped distribution system (**Figures 11-14**) in both the DDA and PDA cases, this type is characterized by the fact that from intake to distribution to the tap, the drinking water network uses pumps continuously. Therefore, the pressure here depends on the type of pump and its characteristic parameters (operating flow rate (*Q*), geodetic head (Hg), total head (HMT)…etc.) and on the varying demands of consumers, such as the water distribution network in the "Lacul Tei" residential area. This is practice.

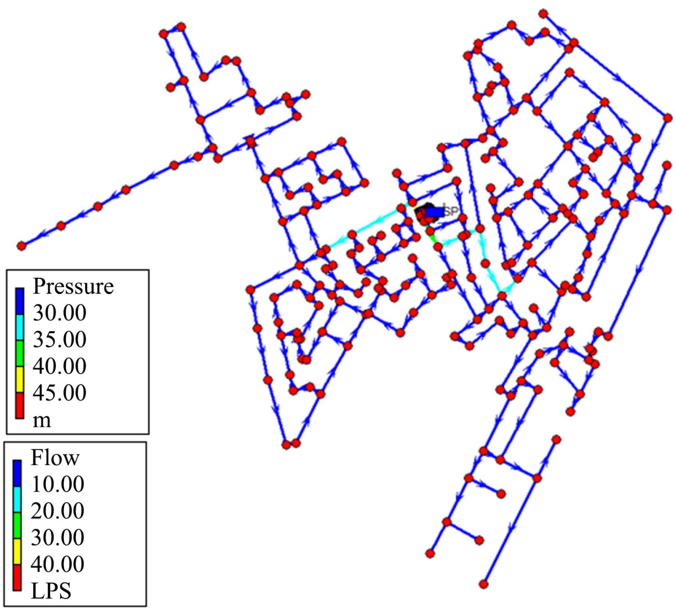

Figure 11. Water distribution network of the Lacul Tei area, simulation: Pressure-flow (DDA case).

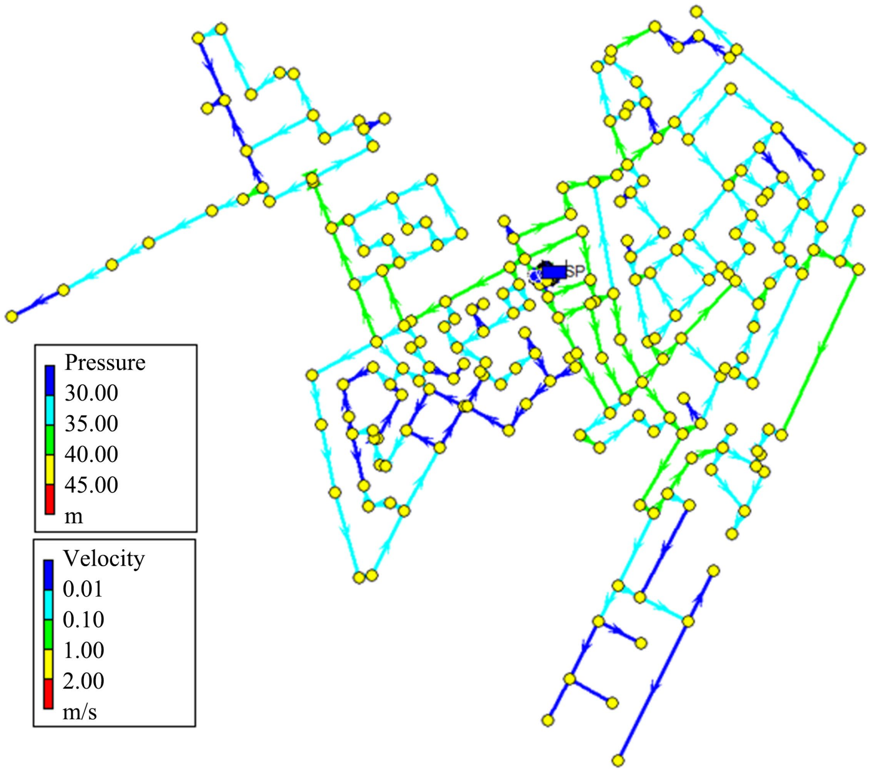

Figure 12. Water distribution network of the Lacul Tei area, simulation: Pressure-velocity (DDA case).

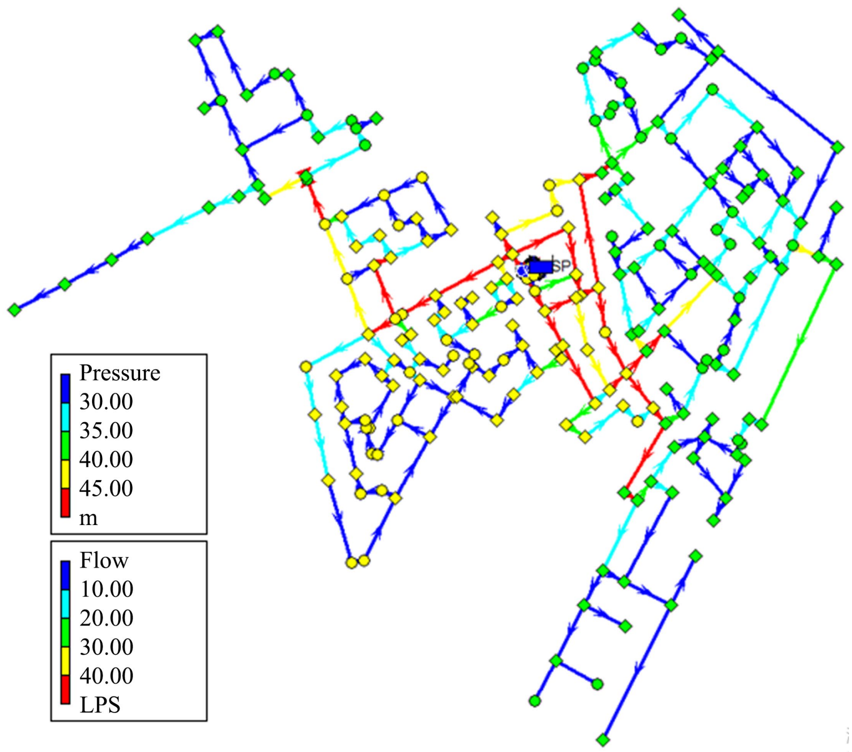

Figure 13. Water distribution network of the Lacul Tei area, simulation: Pressure-flow (PDA case).

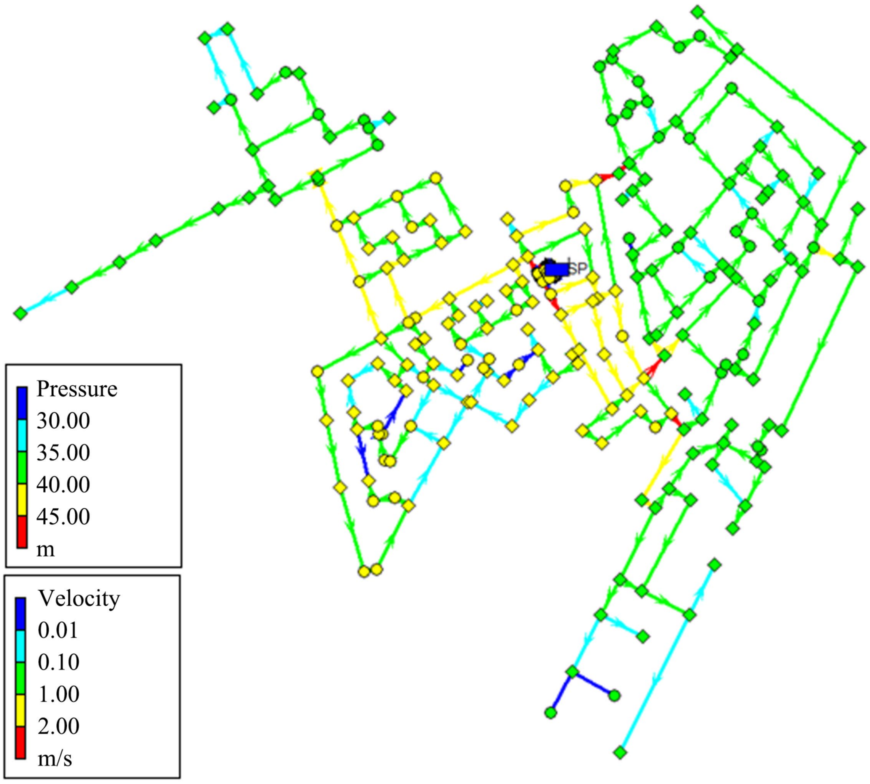

Figure 14. Water distribution network of the Lacul Tei area, simulation: Pressure-velocity (PDA case).

In EPANET, when performing a Pressure Driven Analysis (PDA), the introduction of discharge coefficients and the emitter exponent has a direct impact on the modeling of flow rates at nodes based on the available pressure.

From what has been observed:

- Unlike Demand Driven Analysis (DDA), where demand at nodes is fixed, PDA adjusts flow rates at nodes based on available pressure.
- When the pressure drops below a certain threshold value, the delivered flow rate is reduced in accordance with the orifice emission Equation (1):

$$q = C \cdot P^{\gamma}$$

where: q: flow rate, c: discharge coefficient. It was determined with a variable value between: (0.176 - 0.510) in the case of Algeria. And between: (0.178 – 0.522) in the case of Romania. This coefficient varies according to the number of apartments on each floor of the building (see Table 6 and Table 10).

P: is the nodal pressure, γ: pressure exponent (generally between 0.5 and 0.6 for orifices), It was determined with a value of 0.6.

The formulas deduced for each of the two cities are:

- City of N'gaous: $q = 0.334p^{0.6}$
- City of Lacul Tei: $q = 0.442p^{0.6}$

We observed that the difference between the two formulas is minimal, due to the type of equipment used by households in either Algeria or Romania.

The same applies when we look at the basic flow rate tables, according to the French standard NF DTU 60.11P1-1. And the Romanian standards (monitorul oficial al româniei, partea i, nr. 1167 bis/6.xii.2022) and standard (STAS 1478-90).

There is a slight difference in the estimated flow rates in buildings, for example, for sinks French standards: 0.20 ℓ/s and Romanian standards 0.15 ℓ/s while for bathtubs 0.33 ℓ/s vs 0.25 ℓ/s. (See Table 1 and Table 2)

The same can be observed for the formula for calculating the simultaneity coefficient, given that in Romania, the formula is as follows: $f_{AR} = \frac{0.83}{\sqrt{N-1}}$; while those applied in Algeria are based on the French standards, which are: $K = \frac{0.8}{\sqrt{x-1}}$.

This slight difference between the two constants (0.8 in the French standards) and (0.83 in the Romanian standards) is:

- The difference between 0.83 and 0.8 comes from experimental data and analyses conducted in each country on how sanitary facilities are used.
- Romania adopted the coefficient of 0.83 based on local studies on the frequency of use and the distribution of water consumption.
- France adopted the coefficient of 0.8 following its own observations on the use of the facilities.
- Furthermore, the difference between these two constants is probably due to several factors:
- Building typology: In Romania and France, the use of sanitary facilities can vary depending on the building type (residential, hotel, industrial, etc.).
- Consumption habits: Depending on lifestyle, the frequency and duration of water consumption points can differ between the two countries.
- Design safety: The slightly higher coefficient in Romania (0.83 versus 0.8) may indicate a more conservative approach, providing a greater safety margin for system design.

Ultimately, the difference between the two coefficients is relatively small (0.83 versus 0.8), but reflects national particularities in terms of water consumption and plumbing design philosophy. Romania adopts a slightly higher value, likely for safety reasons and to adapt to the specific requirements of local infrastructure.

- Pressure at Nodes:

In demand-based analysis, there is an exaggeration of pressure at nodes. As shown in Figure 7 and Figure 11, red indicates high or very high pressures, which can signal overpressure zones, which can be problematic for equipment.

Unlike pressure-based analysis (PDA), the pressure in Figure 9 and Figure 10 and Figure 13 and Figure 14, where green indicates and represents pressures in the average range, which is often the desired pressure in the network.

In short:

- If the pressure at the node is insufficient (close to zero), the delivered flow decreases considerably or even reaches zero.
- If the pressure is sufficient or exceeds the operating pressure, the flow reaches the nominal demand defined in the model.

8.3. Pipe Diameters

- When designing a network, a DDA-based model could lead to an overestimation of diameter requirements, as the calculations assume full demand satisfaction.
- In PDA, since demand varies with pressure, the model can help identify network sections requiring reinforcement (increased diameters) to improve distribution.

For example, in **Figure 9** and **Figure 10** and **Figure 13** and **Figure 14**, the red pipe sections appear to require modification since they represent higher flow rates and indicate pipes near their maximum capacity or very high flow rates in response to significant demand or possibly leaks.

Regarding coefficient calibration, taking into account the discharge coefficient and the emitter exponent allows for a more realistic simulation of network behavior under low-pressure conditions in EPANET with PDA.

- Regarding the comparison between Demand-Driven Analysis (DDA) and Pressure-Driven Analysis (PDA)

In EPANET, when comparing a Demand-Driven Analysis (DDA) model and a Pressure-Driven Analysis (PDA) model, it is essential to understand their fundamental differences and how discharge coefficients and the emitter exponent influence the results.

- Demand Driven Analysis model (DDA)

In this model:

- Demand at nodes is fixed and always satisfied, regardless of the pressure level.
- It assumes that the network can always supply the requested flow, which is unrealistic in the case of insufficient pressure.
- It does not take into account the effect of pressure variations on the water supply.
- Pressure Driven Analysis model (PDA)

In this model:

- The supplied flow depends on the pressure available at each node.
- If the pressure is below a critical value, the distributed flow rate decreases according to a pressure-flow rate relationship defined by the transmitter.

9. Conclusions

This study focused on calibrating water distribution network models by determining the discharge coefficient (C) and pressure exponent (γ) essential for pressure-driven hydraulic simulations using EPANET 2.2. Two real-world case studies N'gaous in Algeria and Lacul Tei in Bucharest, Romania were analyzed, representing gravity-fed and pumped systems respectively.

The results demonstrated strong convergence toward a pressure exponent value of $\gamma = 0.6$, consistent with theoretical expectations for orifice-type flows. The discharge coefficient C was found to vary with building occupancy, ranging from 0.176 to 0.510 in Algeria and from 0.178 to 0.522 in Romania. Empirical formulas were derived for each case, enabling more accurate modeling of pressure-dependent flow behavior.

The minor differences observed between the two case studies are primarily attributed to local plumbing standards, building typologies, and lifestyle differences affecting water consumption habits. Specifically, variations in flow requirements for individual fixtures and in simultaneity coefficients (0.8 for the French standard versus 0.83 for the Romanian standard) were noted but had a limited impact on the overall calibration.

When comparing Demand Driven Analysis (DDA) and Pressure Driven Analysis (PDA), the study highlighted PDA's superior ability to simulate real-world conditions, particularly under low-pressure scenarios. PDA models revealed potential system vulnerabilities—such as undersized pipes or pressure deficiencies that DDA models tend to overlook

Importantly, this methodology offers significant value during the design phase of water distribution systems, where physical measurements are unavailable and decisions must rely on regulatory standards and theoretical modeling. By linking national plumbing norms to hydraulic simulation parameters, the study provides a practical framework for engineers to estimate consumption patterns and pressure dynamics with greater confidence.

While the approach is grounded in normative data, future research should incorporate field measurements to enhance model precision and account for real-world complexities such as leakage, behavioral variability, and infrastructure aging. Nonetheless, this work fills a critical gap in the literature by reconciling regulatory standards with simulation calibration, offering a replicable and adaptable method for international applications. Ultimately, adopting Pressure Driven Analysis (PDA) with context-specific calibration improves network design, operational resilience, and long-term planning for water utilities.

There are, of course, coherent studies worldwide that led to the development of the algorithms used in the new version of EPANET, but to our knowledge, no approach has been undertaken to attempt to reconcile the coefficients used in the mathematical models with the regulations in force in different countries and to compare these coefficients.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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