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Determination of Implementation Cost Indicators for Water Supply Systems in the State of Pará, Brazil, as a Subsidy for the Elaboration of Economic-Financial Feasibility Studies

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ABSTRACT
The research aimed to establish indicators for measuring the implementation costs of Water Supply Systems in the context of preparing economic-financial feasibility studies. To achieve this, the total implementation costs of 09 (nine) Water Supply Systems in Pará were surveyed and systematized, related to ongoing or recently completed projects in municipalities of the state; resulting in the identification of the system components, the establishment of cost indicators, and the validation of these indicators through the application of the methodologies of Jungles (1994) – adapted by Costa (2003) – and the National Secretary for Environmental Sanitation (2010). With the completion of this study, the current coverage and the projected increase in service provision were assessed through the implementation of interventions outlined in the scope of the construction, expansion, and improvement works of WSSs. Additionally, by establishing cost indicators for each unit within the Systems, it was possible to evaluate the convergence or divergence of the calculated indicators; notably, indicators for RWPS, RWP, SR, and ELR units exhibited a greater tendency toward centralization. In conclusion, based on the proposed validation, it was found that the methodology by Jungles (1994) did not accurately represent the estimated implementation costs for any of the units, whilst the methodology of the National Secretary for Environmental Sanitation (2010), due to minimal percentage differences, is more suitable for estimating overall budgets for basic sanitation system units.

KEYWORDS: Costs. Indicators. Water supply systems.

1 INTRODUCTION

The rapid growth of the Brazilian population in major urban centers has increased the demand for potable water over the last decades, however, in many areas there has not been a proportional expansion of coverage and service provision through public water supply systems. This phenomenon resulted in a deficit in population coverage, posing a significant challenge for current public administrators, service providers, and other social actors involved in the process (Barros et al., 2017).

This situation is illustrated by the indicators available in the National Sanitation Information System (Brazil, 2020), with 70.30% of the country's population being served by a water supply system and average indicators of 39.87% of distribution network losses and only 46.22% of metering of water mains, which highlights the need to expand infrastructure and enhance the efficiency of public water supply systems in Brazil.

In this context, it is imperative the improvement of operational and commercial management of water supply service providers through the control and reduction of losses and the efficient management of water demand in Water Supply Systems (WSSs) (Alegre et al., 2006); considering that these actions directly impact the operating expenses of the systems.

Therefore, it is necessary for these expenses to be estimated in the project elaboration phase, considering that the various conception alternatives for each Water Supply System (WSS) directly impact the expenses of each system. These are related to the costs for the implementation of the systems (Marques, 2016; Andrade Sobrinho and Borja, 2016).

After the technical-economic feasibility study of conception alternatives, where the implementation costs and projected operating expenses for each WSS alternative are measured, the service provider will be able to indicate, through the analysis of criteria related to economic-financial, technical, institutional, environmental, and social aspects, the system configuration that will be more thoroughly detailed in the project phase. This includes considerations

ISSN 1980-0827 – Volume 20, Number 1, Year 2024

regarding the raw water intake source (Pará, 2020).

In this context, several methodologies have been developed for the measure of implementation costs of Water Supply Systems (WSSs) in the early stages of study and project development, notably those of Jungles (1994) and the SNSA – National Secretary for Environmental Sanitation (2010).

Jungles (1994), updated by Costa (2003), developed a mathematical model for measuring the implementation costs of units such as Raw Water Pumping Station (RWPS), Raw Water Pipeline (RWP), Water Treatment Plant (WTP), Supported Reservoir (SR), Elevated Reservoir (ELR), and Water Distribution Network (WDN); with aim to gather capacity variables that could reflect on productive costs. Meanwhile, the technical team of the National Secretariat for Environmental Sanitation, part of the Ministry of Regional Development, established reference costs for the preparation of global budgets for basic sanitation systems, including WSSs, as a subsidy for investment management and the qualification of public spending on urban infrastructure (Brazil, 2010).

In addition to implementation costs, the raw water intake source must be determined during the study of conception alternatives, considering the direct impact of this definition on various elements to be designed and/or defined. This includes the extent of conveyance lines, water treatment technology, system components, and the implementation and operation costs of the WSS (Ferreira et al., 2020).

Despite the economic feasibility study of conception alternatives providing subsidies for decision-making regarding the configuration of WSSs, it is still relatively unknown and underutilized by stakeholders involved in activities within municipal administrations, regulatory agencies, sanitation companies, as well as organized civil society.

This lack of awareness weakens decision-making and the improvement of managerial processes, as well as the participation and social control in the provision of water supply services; perpetuating inefficient operational practices (Barros et al., 2017). Thus, it is imminent to measure the impact of different configurations of WSSs, especially in terms of raw water intake, on the expenses inherent to the Systems. This notably includes the costs required for the implementation of WSS infrastructure.

Therefore, considering the limited availability of studies investigating the impact of system configuration on the implementation costs of Water Supply Systems (WSSs), this study will compile and systematize implementation cost indicators for WSSs in the state of Pará. This will be based on the analysis of 09 (nine) budget spreadsheets related to ongoing or recently completed projects; aiming to measure these implementation costs in the preparation of economic-financial feasibility studies.

Periódico Eletrônico "Fórum Ambiental da Alta Paulista"
Electronic Journal "Environmental Forum of Alta Paulista"

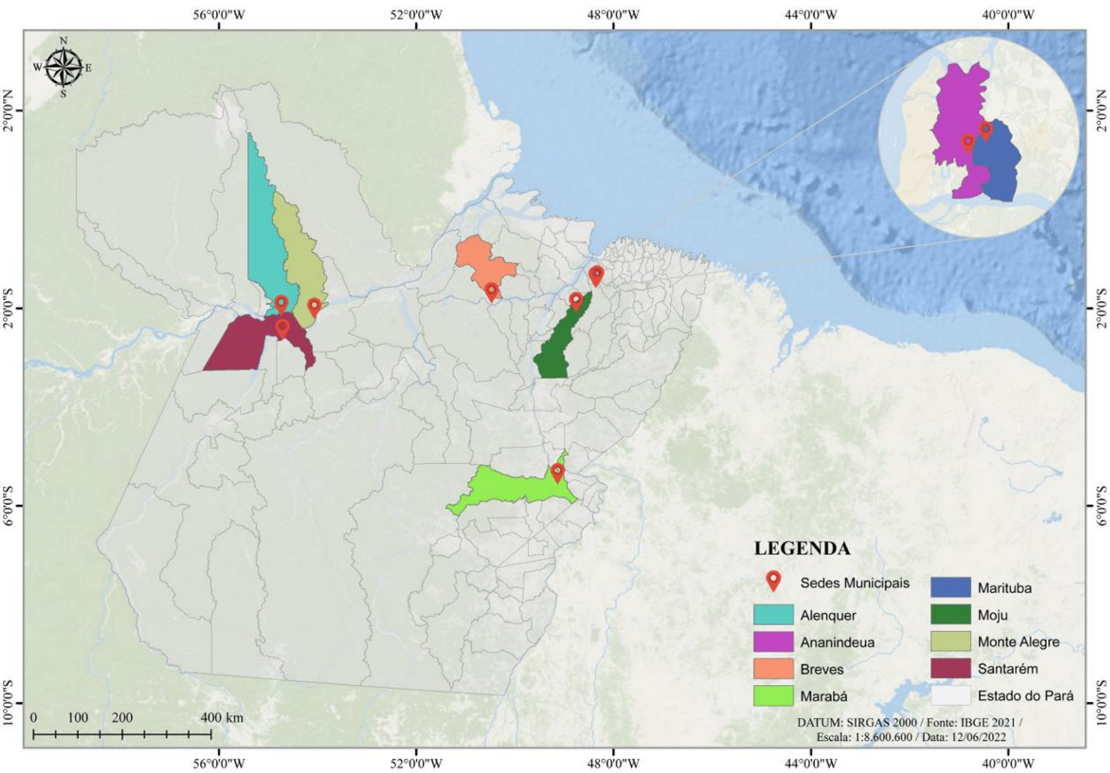
ISSN 1980-0827 – Volume 20, Number 1, Year 2024

2 METHODOLOGY

2.1 Description of Performed Activities

To perform this research, the total implementation costs of 09 (nine) Water Supply Systems in the state of Pará were surveyed. These costs pertain to ongoing or recently completed projects in the municipalities of Alenquer, Ananindeua – Águas Lindas neighborhood, Breves, Marabá, Marituba – Beija-Flor Housing Complex, Moju, Monte Alegre, and Santarém – Urban Center and Alter do Chão District, as illustrated in Figure 1.

Figure 1 – Location of municipalities in the state of Pará with ongoing or recently completed projects of Water Supply Systems.



Source: Author's own work (2022).

The state of Pará is one of the 26 states of the Federative Republic of Brazil, located in the Northern Region of the country. According to data from the Brazilian Institute of Geography and Statistics (Brazil, 2022), the estimated resident population of the state in the year 2021 was 8,777,124 inhabitants, with a total area of 1,245,870.70 km² – making it the second-largest in the country. This results in a population density of 6.07 inhabitants/km².

After the collection of these costs, they were detailed by the System component, namely: intake, conveyance, storage, and distribution. To enable cost comparison among Systems, the base date of the respective budgets was standardized to May 2022, applying the accumulated National Index of Civil Construction Prices (INCC).

The INCC was created with the intention of measuring the evolution of costs in

ISSN 1980-0827 – Volume 20, Number 1, Year 2024

residential constructions, establishing itself as the country's first official index of civil construction costs. It has a historical series dating back to January 1944 (Portal Brasil, 2017).

Subsequently, unit cost indicators were determined per unit of the Water Supply System (WSS) – BRL/m³.h, BRL/m³, BRL/Km, BRL/inhab. or BRL/Connection. Additionally, based on total costs, the projects were grouped according to their respective magnitudes – small, medium, and large.

Finally, to validate the results, the methodologies developed by Jungles (1994) and the National Secretary for Environmental Sanitation (2010) were applied, comparing the estimated costs obtained through the application of these methodologies with the actual budget spreadsheets of the initially surveyed projects.

2.2 Description of Applied Methodologies for Validation of Implementation Costs

The equations derived from the methodology of Jungles (1994), adapted by Costa (2003), for each component unit of the Water Supply System, are compiled in Box 1.

Box 1 – Equations for measuring the implementation costs of Water Supply Systems (WSSs).

Components of the System	Mathematical Model
Lifting Stations	$Y_1 = 730.14 * L_1{}^{0.340} * X_1{}^{0.750}$
PVC Conduits	$Y_2 = 2.24 L_2{}^{1.279} * X_2{}^{0.214}$
Steel Conduits	$Y_3 = 31.17 L_3{}^{0.872} * X_3{}^{0.362}$
Treatment Plant	$Y_5 = 1{,}200.36 X^{0.969}$
Reservoirs	$Y_4 = 31{,}186.13 X_4{}^{0.610}$
Distribution Network	$Y_6 = 171.81 L_6{}^{0.540} X_6{}^{0.530}$

Source: Jungles (1994); Costa (2003).

Where: "X" is the installed capacity, "L" is the length/height, and "Y" is the implementation cost per stage/unit.

Additionally, the methodology developed by the National Secretary for Environmental Sanitation was based on the following premises:

- Classification of a total of 270 Synthesis of Approved Projects (SPAs) forms, financed by the Growth Acceleration Program (PAC), with 125 related to Water Supply Systems (WSSs), covering 2,000 to 100,000 families per system, located in all regions of the country – North, Northeast, Midwest, Southeast, and South;
- For each category, costs information from the SPAs was appropriated and segregated according to the stages/component units of the WSS – intake, RWPS, RWP, WTP, SR / ELR, WDN, and household connection;
- Calculation of the mean, standard deviation, and derivation of the equation and respective trend curve of values according to the aforementioned criteria.

The reference indicators determined by the technical team of the Secretariat are listed in Box 2.

ISSN 1980-0827 – Volume 20, Number 1, Year 2024

Box 2 – Reference Indicators for the Implementation of Water Supply Systems in the Northern Region.

Indicator	**Specification**	**Cost per Inhabitant ($\mathrm{BRL}/\boldsymbol{inhab}.$)**	**Service Coverage (Households)**
IAA_CG	Composition of the Overall Cost of the Water Supply System per inhabitant as a household occupant (IBGE, 2008)	543.00	$1{,}000 < D < 2{,}000$
		429.00	$2{,}001 < D < 4{,}000$
		360.00	$4{,}001 < D < 10{,}000$
		286.00	$10{,}001 < D < 20{,}000$
		224.00	$20{,}001 < D < 34{,}000$
		208.00	$34{,}001 < D < 64{,}000$

Source: Brasil (2010).

Note: *Cost, in BRL/inhab., per component unit – Intake, Pumping Station, Conveyance, Treatment, Reservoir, Distribution Network, and Household Connection – and Overall of implemented Water Supply Systems (WSSs) in the Northern Region of the country; regardless of the water source or system configuration.*

Additionally, the percentage values were determined for each component of the Water Supply System, as per Box 3.

Box 3 – Reference for the percentage composition of the overall cost for Water Supply Systems in the Northern Region.

Indicator	Specification	Percentual							
		Intake	LPS	Conveyance	WTP	Reservoir	Network	Connection	Overall
IAA_CG %	Percentage Composition of the Water Supply System Cost	7	10	14	17	10	23	19	100

Source: Brasil (2010).

3 RESULTS

3.1 Identification of Component Units of WSSs

For the calculation of implementation cost indicators of Water Supply Systems (WSSs) in the state of Pará, information was gathered by component units of the systems, as detailed in Table 1.

Periódico Eletrônico "Fórum Ambiental da Alta Paulista"
Electronic Journal "Environmental Forum of Alta Paulista"

ISSN 1980-0827 – Volume 20, Number 1, Year 2024

Table 1. Details of the constituent units of Water Supply Systems under implementation in the municipalities of Alenquer and Breves.

Unidades	Alenquer	Breves
RWPS	Intake from the Paraná do Alenquer River – 02 CMBs (Operation 1 + 1), Q = 142 L/s, Hman = 21 mca and P = 75 cv	Intake from the Parauhaú River – 02 CMBs (Operation 1 + 1), Q = 644,07 m³/h, Hman = 14 mca and P = 60 cv
RWP	L = 998 meters, DN 450 mm in HDPE	L = 132 meters of Ø300 mm in HDPE
WTP	Q = 511,20 m³/h (142 L/s)	Q = 644,07 m³/h
SR	V = 1500 m³	V = 1.000 m³
TWPS	TWPS 01 (SR → ELR SECTOR 01) – Operation 1 + 1, Q = 257,26 m³/h (71,46 L/s), Hman = 33,02 mca and P = 40 hp TWPS 02 (SR → Existing ELR 02) – Operation 1 + 1, Q = 200,00 m³/h (55,55 L/s), Hman = 42 mca and P = 40 hp	EEAT 01 (SR → Existing ELR 01) – Operation 1 + 1, Q = 187,15 m³/h, Hman = 38 mca and P = 50 cv TWPS 02 (SR → ELR 02/Planned) – Operation 2 + 1, Q = 228.,6 m³/h, Hman = 32 mca and P = 50 cv
TWP	TWP 01 (TWPS 01) – L = 74,50 meters of Ø250 mm in PVC OfFoFo TWP 02 (TWPS 02) – L = 2.01 Km of Ø250 mm in PVC DEFoFo	TWP 01 (TWPS 01) – L = 1,694 Km of Ø250 mm in PVC DEFoFo TWP 02 (TWPS 02) – L = 56 meters of Ø300 mm in Cast Iron
ELR	02 RELs – V = 500 m³	V = 830 m³
WDN	L = 38,445 Km	L = 14,127 Km
Connections	2.226 units	1.693 units

Source: Author's own work (2022).

The population served by the public water supply system in the municipality of Alenquer in 2011 was 10,756 inhabitants, equivalent to a coverage of 49.40% in the urban area at that time. The expectation, with the completion of the works, is that there will be universal coverage for the urban population by the end of the plan, which will be 33,845 inhabitants in 2030; equivalent to a flow rate of 122.22 L/s or 440 m³/h. It is emphasized that the planned connections aim to serve 11,353 inhabitants, corresponding to 33.54% of the final planned population (2030).

Simultaneously, the expectation with the completion of the expansion works of the WSS in the municipality of Breves is that there will be universal coverage for the urban population by the end of the plan (2030), which will be 53,673 inhabitants in 2030; equivalent to a flow rate of 178.91 L/s or 644 m³/h, with household connections for 8,465 inhabitants (15.77%) of the population to be served.

The details of the constituent units of the recently completed or ongoing works of the WSSs in the municipalities of Marabá, Moju (WSSs with surface water intake), and Ananindeua – Águas Lindas neighborhood, Marituba – Beija-Flor Housing Complex, Monte Alegre, and Santarém – Urban Center and Alter do Chão District (WSSs with underground water intake) are provided in the supplementary files.

The expectation, with the completion of the expansion works of the public water supply system in the municipality of Marabá, is that there will be universal coverage for the urban population by the end of the plan, which will be 311,198 inhabitants in 2028; equivalent to a flow rate of 864.44 L/s or 3,112 m³/h. It is noteworthy that the planned water distribution network aims to cover 26,143 inhabitants – corresponding to 8.40% of the projected population,

ISSN 1980-0827 – Volume 20, Number 1, Year 2024

while the planned connections aim to effectively serve 30,245 inhabitants – corresponding to 9.71% of the urban population.

Finally, with the completion of the expansion works of the WSS in the municipality of Moju, there is an expectation of achieving universal coverage for the urban population by the end of the plan, which will be 43,815 inhabitants in 2030 – a flow rate of 162.28 L/s or 584.21 m³/h. It is emphasized that the planned connections aim to serve a portion of this total population, specifically 14,150 inhabitants – or 32.29% of the projected population.

It is highlighted that the WSSs presented from this point forward have groundwater as the water source. In this context, with the completion of the expansion works of the SAA in the Águas Lindas neighborhood, located in the municipality of Ananindeua, there is a forecast to serve 58.86% of the urban population by the end of the plan (2030) in the locality – 45,998 inhabitants, corresponding to a flow rate of 127.77 L/s or 460 m³/h. The remaining population is expected to be served upon the completion of the interventions in the 2nd Stage, currently in the project development phase. It is noteworthy that the planned connections aim to serve 30,270 inhabitants, corresponding to 65.80% of the inhabitants to be served in the 1st Stage.

In turn, the expectation, with the completion of the expansion works of the Water Supply System (SAA) in the Beija-flor Housing Complex, located in Marituba, is that there will be universal coverage for the urban population by the end of the plan for the locality, which will be 41,249 inhabitants in 2030; equivalent to a flow rate of 152.77 L/s or 550 m³/h. It is noteworthy that the planned connections aim to serve 9,875 inhabitants, corresponding to 23.93% of the urban population in the year 2030.

Simultaneously, with the completion of the expansion works of the WSS in the Urban District of the municipality of Santarém, the expectation is for universal coverage for the urban population by the end of the plan for the locality, which will be 82,098 inhabitants in 2030 – a flow rate of 228.05 L/s or 820.98 m³/h. It is worth noting that the costs related to the implementation works of the SAA in Santarém for the other units could not be obtained.

With the completion of the expansion works of the WSS in the District of Alter do Chão, located in Santarém, there is an expectation of universal coverage for the urban population by the end of the plan for the locality, which will be 14,510 inhabitants in 2033; equivalent to a flow rate of 53.74 L/s or 193.47 m³/h. It is important to highlight that, due to the district being a tourist location with population seasonality based on the time of year, the final plan population considers the predicted population increase of 80%. Additionally, it is emphasized that the planned connections aim to serve 10,650 inhabitants, corresponding to 73.40% of the final plan population (2033).

Eventually, the population served by the WSS in the municipality of Monte Alegre in 2007 was 17,237 inhabitants, equivalent to a coverage of 66.16% in the urban area at that time. The expectation, with the completion of the works, is that there will be universal coverage for the urban population by the end of the plan, which will be 39,480 inhabitants in 2027 – a flow rate of 109.67 L/s or 394.81 m³/h. It is emphasized that the planned connections aim to effectively serve 19,150 inhabitants – corresponding to 48.50% of the urban population for the year 2027.

ISSN 1980-0827 – Volume 20, Number 1, Year 2024

Finally, based on the survey of the selected components of the Water Supply Systems (SAAs), the following quantity of available information is observed, summarized in

Box 4.

Box 4 – Municipalities whose works to expand/implement WSSs presented cost information per component unit of the System.

WSS units	Superficial	Groundwater
Intake/RWPS	Alenquer, Breves e Moju	–
Intake	–	Beija-flor, Alter do Chão e Santarém
RWPS		Águas Lindas e Monte Alegre
RWP	Alenquer, Breves e Moju	Beija-flor, Alter do Chão e Santarém
WTP	Alenquer, Breves, Marabá e Moju	Beija-flor
SR	Alenquer, Breves e Moju	Beija-flor e Alter do Chão
TWPS	Alenquer, Breves, Marabá e Moju	Águas Lindas, Beija-flor e Alter do Chão
TWP	Alenquer, Breves, Marabá e Moju	Águas Lindas e Monte Alegre
ELR	Alenquer, Breves, Marabá e Moju	Beija-flor e Alter do Chão
WDN	Alenquer, Breves, Marabá e Moju	Águas Lindas, Beija-flor, Alter do Chão e Monte Alegre
Connections	Alenquer, Breves e Moju	–
Metered Connections	–	Águas Lindas, Beija-flor, Alter do Chão e Monte Alegre
Water Meters		Monte Alegre

Source: Author’s own work (2022).

3.2 Calculation of Cost Indicators

After gathering information on the components of the systems, the implementation cost indicators for Water Supply Systems (WSS) in the state of Pará were calculated, as detailed below.

- Intake/Raw Water Pumping Station (RWPS)

The implementation cost indicators related to the systems, specifically the Intake/EEAB unit, as well as the calculation of averages and standard deviations, are compiled below in Table 2 and Table 3.

Table 2. Implementation Cost Indicators for Intake/EEAB (Surface Water Supply Systems).

Work	Intake/RWPS Indicators	
	$BRL/m^3.h$	$BRL/inhab.$
Alenquer	12,027.96	181.67
Breves	5,067.03	60.80
Moju	3,332.58	45.64
AVERAGE	**6,809.19**	**96.04**

ISSN 1980-0827 – Volume 20, Number 1, Year 2024

STANDARD DEVIATION	**3,757.55**	**60.87**

Source: Author's own work (2022).

Table 3. Cost implementation indicators for the Raw Water Intake/Pumping Station (Subterranean WSS).

Work	**Intake Indicators**		**Work**	**RWPS Indicators**	
	$BRL/m^3.h$	$BRL/$ $inhab.$		$BRL/m^3.h$	$BRL/$ $inhab$
Beija-flor	5,616.15	85.78	Águas Lindas	102.35	1.89
Alter do Chão	5,757.74	83.33			
Santarém	6,660.77	81.13	Monte Alegre	1,414.31	4.73
AVERAGE	**6,011.55**	**83.41**	**AVERAGE**	**758.33**	**3.31**
STANDARD DEVIATION	**462.69**	**3.60**	**STANDARD DEVIATION**	**655.98**	**1.42**

Source: Author's own work (2022).

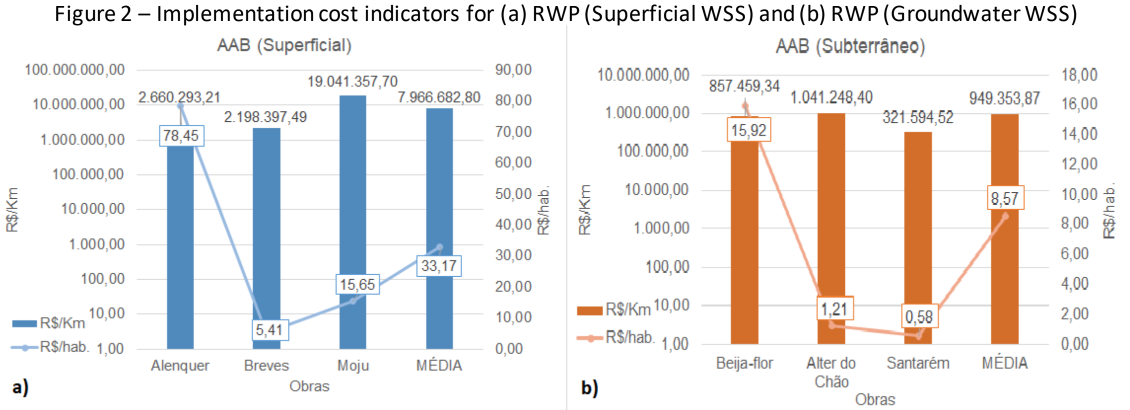
From the indicators in Table 3, it can be observed that the average cost for implementing the raw water intake unit in the WSS with a superficial water source is BRL 6,809.19/m³.h, while the analogous cost for WSS with a groundwater source is BRL 6,011.55/m³.h. Additionally, despite the close values, the standard deviation of the average cost in BRL/m³.h for WSS with groundwater intake was lower, indicating a tendency for data centralization. Moreover, it is noteworthy that the costs of the raw water intake unit in WSS with a superficial water source are convergent in BRL/hab., as evidenced by the small standard deviation of BRL 3.60/hab.

The indicators of implementation costs related to water supply systems, specifically the RWP unit, as well as the calculation of averages, are presented below in Figure 2.

- Raw Water Pipeline (RWP)

The indicators of implementation costs related to water supply systems, specifically the RWP unit, as well as the calculation of averages, are presented below in Figure 2.

Figure 2 – Implementation cost indicators for (a) RWP (Superficial WSS) and (b) RWP (Groundwater WSS)



Source: Author's own work (2022).

Through the indicators above, it can be observed that the average cost for the

ISSN 1980-0827 – Volume 20, Number 1, Year 2024

implementation of RWP in a superficial source WSS is BRL 7,966,682.80/Km, whereas the corresponding cost for WSS with groundwater source is BRL 949,353.87/Km; indicating significantly different costs between them.

One hypothesis for the observed discrepancy between RWPs in surface intake WSS and those in groundwater intake can be attributed to the tendency for aducts in Systems of the first type to have shorter lengths, considering that usually the water intake point is not too far from the destination point of the pumped volume, typically the WSS's own WTP. Meanwhile, aducts in groundwater WSS tend to be longer due to, for example, the recommendation of a minimum distance between two wells to avoid overlapping of their drawdown cones; causing issues in the exploitation of raw water and, consequently, affecting the lifespan of the groundwater intake unit.

- Water Treatment Plant (WTP)

Cost implementation indicators for the systems, specifically for the water treatment unit, along with the calculation of the mean and standard deviation, are presented in Table 4:

Table 4. Indicators of implementation costs for the water treatment unit (Superficial WSS).

Work	WTP (Superficial) Indicators	
	$BRL/m^3.h$	$BRL/inhab.$
Alenquer	21,827.94	329.69
Breves	12,167.22	146.01
Marabá	7,811.01	80.32
Moju	13,860.13	189.80
AVERAGE	**13,916.58**	**186.45**
STANDARD DEVIATION	**5,072.75**	**91.42**

Source: Author's own work (2022).

It is worth noting that, due to the information being gathered and the costs systematized for only one iron removal WTP, applicable as a treatment unit for the Underground WSS, the average and standard deviation were not calculated for this category. The mentioned ETA refers to the station in the WSS of Beija-flor Housing Complex, in the municipality of Marituba; with calculated cost indicators of BRL 5,742.85/m³.h and BRL 77.97/inhabitant.

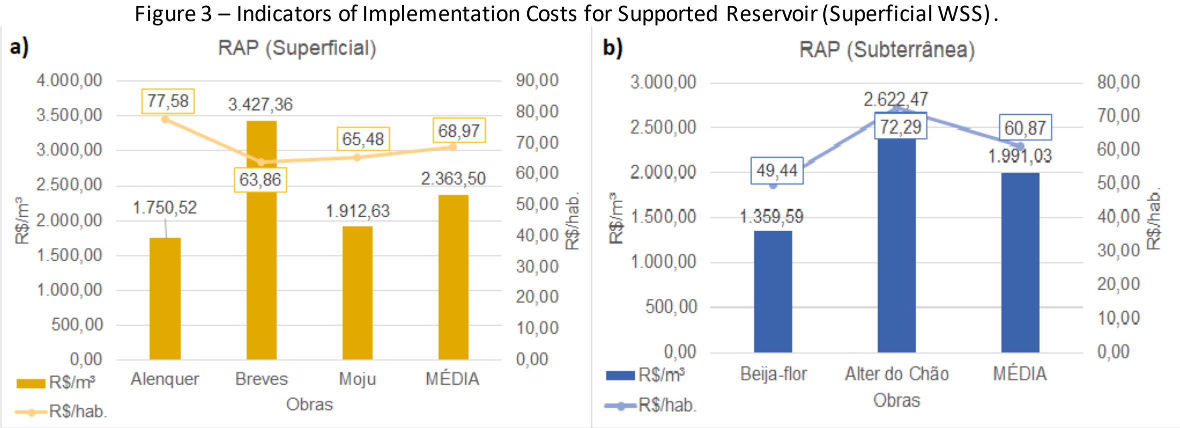
- Supported Reservoir (SR)

The indicators of implementation costs related to the systems, specifically for the supported reservoir unit, as well as the calculation of averages and standard deviations, are presented in Figure 3.

Periódico Eletrônico "Fórum Ambiental da Alta Paulista"
Electronic Journal "Environmental Forum of Alta Paulista"

ISSN 1980-0827 – Volume 20, Number 1, Year 2024

Figure 3 – Indicators of Implementation Costs for Supported Reservoir (Superficial WSS).



Source: Author's own work (2022).

From the indicators in Figure 3, it can be observed that the average cost for the implementation of the reservoir unit in WSS with a superficial water source is BRL 2,363.50/m³, while the analogous cost for WSS with an underground water source is BRL 1,991.03/m³. Additionally, despite the close values, the standard deviation of the average cost in BRL/m³ for WSS with underground intake was lower, indicating a trend of data centralization.

Additionally, it is worth noting the convergence of costs for the intake unit in WSS with a superficial and underground water source in BRL/inhab., expressed by the respective standard deviations – BRL 6.12/inhab. and BRL 11.43in/hab. This convergence was expected, considering that, regardless of the water source for raw water intake, the reservoir unit is not affected; moreover, water supply service providers tend to adopt institutional models for the design and installation of these units.

- Treated Water Pipeline (TWP)

The implementation cost indicators related to the systems, specifically the TWC unit, along with the calculation of averages, are compiled in Table 5:

Table 5. Implementation cost indicators for the treated water pipeline unit (Superficial and Groundwater WSSs).

Work	RWP (Superficial) Indicators		Work	RWP (Groundwater) Indicators	
	BRL/Km	$BRL/hab.$		BRL/Km	$BRL/hab.$
Alenquer	2,060,327.29	126.89	Águas Lindas	5,072,164.94	2.21
Breves	1,856,993.97	2.73			
Marabá	1,672,873.21	12.04	Monte Alegre	1,691,314.67	17.24
Moju	1,978,197.88	91.16			
AVERAGE	**1,892,098.09**	**58.21**	**AVERAGE**	**3,381,739.80**	**9.72**
STANDARD DEVIATION	**145,779.01**	**52.47**	**STANDARD DEVIATION**	**1,690,425.14**	**7.52**

Source: Author's own work (2022).

From the indicators in Table 5, it can be observed that the average cost for the implementation of the treated water pipeline unit in a superficial intake WSS is BRL

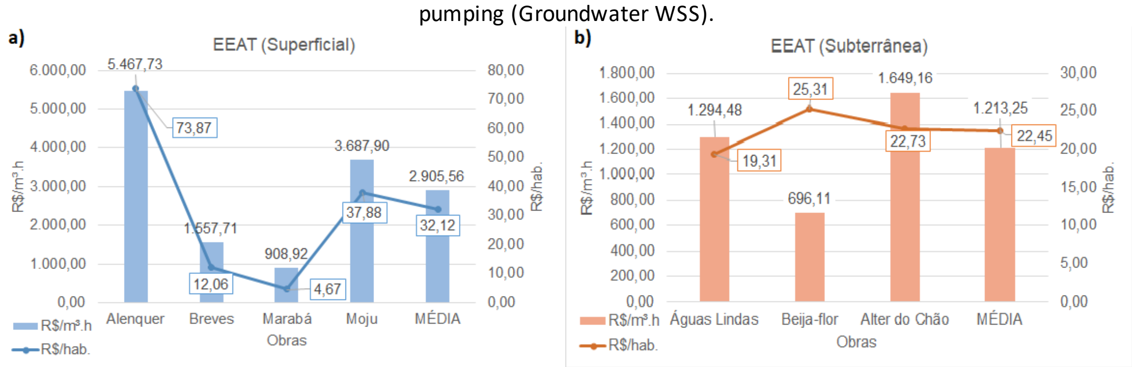
ISSN 1980-0827 – Volume 20, Number 1, Year 2024

1,892,098.09/km, while the analogous cost for a groundwater intake WSS is BRL 3,381,739.80/km. Additionally, the standard deviation of the average cost in BRL/km for a superficial intake WSS was lower, indicating a trend of greater centralization of the data. Furthermore, it is noteworthy that the costs of the treated water pipeline unit in a groundwater intake WSS converge in BRL/inhab., expressed by the small standard deviation – BRL 7.52/hab.

- Treated Water Pumping Station (TWPS)

In Figure 4, the cost implementation indicators for the studied systems are consolidated, specifically for the EEAT unit, along with the calculation of their respective averages.

Figure 4 – Implementation cost indicators for (a) treated water pumping (Superficial WSS) and (b) treated water pumping (Groundwater WSS).



Source: Author's own work (2022).

From the indicators in Figure 4, it can be observed that the average cost for implementing RWPSs in a superficial intake WSS is BRL 2,905.56/m³.h, while the analogous cost for a groundwater WSS is BRL 1,213.25/m³.h, indicating distinct costs between them.

Uma hipótese para a discrepância observada entre as EEATs em SAA com captação em manancial superficial e em manancial subterrâneo pode ser atribuída à envergadura dos Sistemas, onde Alenquer, Breves e Moju (Figura 4a) podem ser classificados como de médio porte e Águas Lindas, Beija-flor e Alter do Chão (Figura 4b) são categorizados como de pequeno porte; o que impacta diretamente nas potências instaladas.

One hypothesis for the observed discrepancy between RWPSs in superficial WSS and groundwater WSS can be attributed to the size of the systems, where Alenquer, Breves, and Moju (Figure 4a) can be classified as medium-sized, while Águas Lindas, Beija-flor, and Alter do Chão (Figure 4b) are categorized as small; which directly impacts the installed capacities.

- Elevates Reservoir (ELR)

The indicators of implementation costs related to the systems, specifically for the elevated reservoir unit, as well as the calculation of averages and standard deviations, are compiled in Table 6.

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Table 6. Implementation cost indicators for elevated reservoir (Superficial and Groundwater WSS).

Work	Elevated Reservoir (Superficial) Indicators		Work	Elevated Reservoir (Groundwater) Indicators	
	$BRL/m^3.h$	$BRL/inhab.$		$BRL/m^3.h$	$BRL/inhab.$
Alenquer	4,299.35	127.03	Beija-flor	4,323.34	52.41
Breves	3,208.54	69.94			
Marabá	3,390.31	10.89	Alter do Chão	2,833.26	58.58
Moju	3,800.90	69.40			
AVERAGE	**3,674.77**	**69.32**	**AVERAGE**	**3,578.30**	**55.49**
STANDARD DEVIATION	**419.61**	**41.06**	**STANDARD DEVIATION**	**608.32**	**3.09**

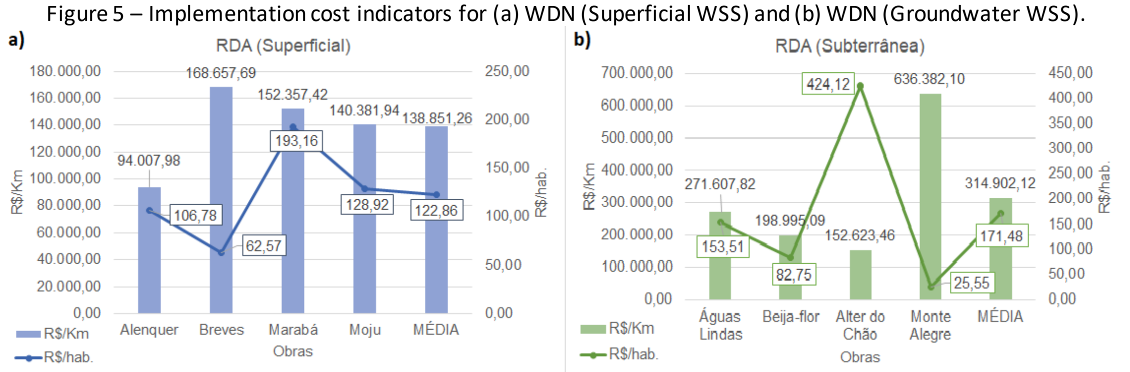
Source: Author's own work (2022).

From the values expressed in Table 6, it can be seen that the average cost for the implementation of the elevated reservoir unit in a superficial intake WSS is BRL 3,674.77/m³, while the analogous cost for an groundwater intake WSS is BRL 3,578.30/m³. Additionally, despite the close values, the standard deviation of the average cost in BRL/m³ for the superficial intake WSS was lower, indicating a trend of greater data centralization. Furthermore, it is noteworthy that the costs of the elevated storage unit in the Underground Water Supply System converged in BRL/inhabitant; expressed by the small standard deviation – BRL 3.09/inhabitant. As with the supported storage unit, there was an expectation of this convergence for the elevated storage unit.

- Water Distribution Network (WDN)

The implementation cost indicators related to the Systems, specifically in the water distribution network, as well as the calculation of averages and standard deviations, are presented in Figure 5.

Figure 5 – Implementation cost indicators for (a) WDN (Superficial WSS) and (b) WDN (Groundwater WSS).



Source: Author's own work (2022).

From the indicators in Figure 5, it is observed that the average cost for implementing WDN in superficial intake WSS is BRL 138,851.26/km, while the analogous cost for groundwater intake WSS is BRL 314,902.12/km; representing distinct costs between them.

One possible explanation for the observed discrepancy between WDNs in superficial intake WSS and the groundwater intake ones could be attributed to the scale of the systems. Medium and large-scale systems like Alenquer, Breves, Marabá, and Moju, due to their higher conveyed flow rates in network sections, tend to have larger pipe diameters, requiring greater excavation volumes for their installation; while the opposite behavior can be observed in small-scale systems like Águas Lindas, Beija-flor, and Alter do Chão. It's worth noting that the Monte Alegre water supply system, categorized as small-scale, exhibited anomalous behavior, considering the high cost per kilometer for installing RDA. It is important to emphasize that considering the removal of the anomalous value, the average implementation cost of WDN in groundwater intake WSS approaches the respective average for systems with surface water sources.

- Household connections

The implementation cost indicators related to the Systems, specifically in the item of connections, along with the calculation of averages and standard deviations, are gathered in Table 7.

Table 7. Implementation cost indicators for connections (Superficial WSS) and metered connections (Groundwater WSS).

Work	Connections (Superficial) Indicators		Work	Metered connections (Groundwater) Indicators	
	$BRL/Unit$	$BRL/inhab.$		$BRL/Unit$	$BRL/inhab.$
Alenquer	2,440.22	48.58	Águas Lindas	300.21	60.04
Breves	591.83	118.37	Beija-flor	489.42	97.88
Moju	292.87	58.57	Alter do Chão	717.03	143.41
			Monte Alegre	530.79	105.33
AVERAGE	**1,108.31**	**75.17**	**AVERAGE**	**509.36**	**101.66**
STANDARD DEVIATION	**949.68**	**30.81**	**STANDARD DEVIATION**	**148.10**	**29.59**

Source: Author's own work (2022).

From the indicators in Table 7, it is observed that the average cost for the implementation of connections in superficial intake WSS is BRL 1,108.31 per unit, while the analogous cost for groundwater intake WSS is BRL 509.36 per Unit; configuring distinct costs between them. This divergence can be explained by the anomalous value (in BRL per Unit) observed in the implementation cost of connections in the Alenquer System, which caused the average for the implementation of connections in Systems with surface water capture to increase.

Furthermore, it is worth noting the convergence of the costs of the capture unit in superficial and groundwater intake WSSs in BRL/inhabitant; expressed by the respective standard deviations – BRL 30.81 per capita and BRL 29.59 per capita.

3.3 Validation of Cost Indicators

After identifying the components of the WSSs and calculating the implementation cost indicators of the systems, the validation of the actual budget sheets of the surveyed works was performed through the estimated costs using the methodologies of Jungles (1994) – adapted by Costa (2003) – and the National Secretary for Environmental Sanitation (2010).

In this context, the Jungles methodology (1994) did not accurately represent the estimated implementation costs of the WSSs compared to the actual costs raised for any of the units – Intake/ RWPS (63.81%), RWP (89.58%), WTP (88.19%), and WDN (95.88%).; refining the conclusion by Barros (2021), who used the same methodology with better results – differences on the order of ±10% between estimated costs and actual values – in measuring the overall implementation costs of WSSs with groundwater sources in the municipality of Belém. Additionally, the mentioned methodology yielded results significantly distant from the actual costs raised in estimating the implementation costs of the reservoir units – SR and ELR; suggesting that its application is not specifically recommended for such units.

Contrary to the application of the first methodology, the method proposed by the National Secretary of Environmental Sanitation (2010) allowed the validation of part of the budgeted costs for the units comprising SAAs, as detailed in Table 8 below.

Table 8. Validation of the actual implementation costs of the surveyed works using the SNSA methodology (2010).

Units	Average Percentage Difference (% ± σ)
Intake/RWPS	41.62 ± 19.9176
RWP	51.92 ± 0.0000
WTP	43.57 ± 35.3043
SR	38.74 ± 10.1031
TWPS	50.56 ± 48.4955
TWP	18.41 ± 12.3229
WDN	46.42 ± 30.1343

Source: Author’s own work (2022).

Upon analyzing Table 8, it is observed that the average percentage differences ranged from 18.41% to 51.92%, while the standard deviations ranged from 10.10% to 48.49%, confirming the better applicability of the methodology developed by the National Secretary of Environmental Sanitation (2010) compared to the Jungles (1994) methodology in estimating overall budgets for water supply systems units as a support for investment management and the enhancement of public spending on basic sanitation infrastructure in Brazil (BRASIL, 2010). Additionally, it is noted that the higher standard deviations observed are associated with units that exhibited greater variability in the sample universe, as previously discussed, notably WTP, RWPS, and WDN.

It is explained that anomalous percentage values were excluded from the sample universe to maintain the internal logic of the dataset within an acceptable range. Additionally, in the data presented in Table 8, there was no division between superficial and groundwater intake WSSs, as both the Jungles (1994) and SNSA (2010) methodologies provide general mathematical formulations per system component, without detailing them based on this particular characteristic of the intake unit.

Finally, as previously highlighted, considering the applicability of the methodology from the SNSA in estimating overall budgets for system units, it is evident that the total implementation costs of 09 (nine) WSSs in the state of Pará are appropriate; consequently, the indicators calculated from these costs are applicable for measuring implementation costs in the context of developing economic and financial feasibility studies for water supply systems.

4. CONCLUSION

Given the limited availability of technical literature establishing indicators for measuring the implementation costs of WSSs in economic and financial feasibility studies, preliminary projects, or basic projects, this study compiled and systematized cost indicators for WSSs in the state of Pará through the analysis of budget spreadsheets related to ongoing or recently completed projects.

Initially, information was gathered to identify the component units of the systems, namely: intake, conveyance, reservation, and distribution. These data, in addition to characterizing the respective systems, allowed for the measurement of current coverage and the expected increase in service coverage following the implementation of interventions outlined in the scope of the planned implementation, expansion, and improvement works of the SAAs.

Furthermore, through the establishment of cost indicators for each component of the systems, it was possible to assess the convergence or lack thereof of the calculated indicators based on their respective means ($\bar{x}$) and standard deviations (σ); with emphasis on the indicators of the units for the elevation of raw water, raw water conveyance, supported and elevated reservoirs, as they showed a higher tendency for centralization.

Finally, through the validation of the actual budget spreadsheets of the surveyed works using the estimated costs obtained through the application of the methodologies of Jungles (1994) and the National Secretary for Environmental Sanitation (2010), it was concluded that the first methodology did not well represent the cost estimation for the implementation of WSSs for any of the units, especially for supported and elevated reservoirs. Meanwhile, through the application of the second methodology, it was concluded that it is more suitable than the first for estimating the overall budgets of basic sanitation system units.

Additionally, it is recommended to conduct studies with a larger sample size, leading to the establishment of specific benchmark indicators for the configuration and location of Water Supply System implementation, as recommended by Barros (2021). This would support cost measurement in the development of economic and financial feasibility studies, contributing to the continued expansion of public system coverage and, consequently, to the universalization of drinking water supply in the country.

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