Benchmarking and performance indicators in Portugal: A case study of a water supply company

Master in Civil Engineering – Building Construction

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Leiria, October of 2021

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Dissertation conducted under the supervision of Professor Ricardo de Jesus Gomes, from the Polytechnic of Leiria (Portugal).

Leiria, October of 2021

Originality and Copyright

This dissertation report is original, made only for this purpose, and all authors whose studies and publications were used to complete it are duly acknowledged.

Dedication

It is with genuine gratitude and warm regard that I dedicate this work to my late parents Lucy and James Lushaba, brother; Mpho Lushaba and the siblings and family that I fortunately still have to this day; Patience Lushaba, Thabo Lushaba and Zinhle Lushaba. Growing up without parents from a very young age, has been by far the most difficult, constantly re-emerging, and unwavering challenge I have faced in life. Even so, the support, guidance and love I have received from my siblings has been incredible and nothing short of extraordinary. Born on the pedestal of greatness; from an academic and an innovator, I am proud to say (with no reservations), that I will live to my fullest potential.

Acknowledgments

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Abstract

Rapid population growth and urbanisation are being experienced worldwide; in industrialised and developing countries alike, although more vigorously in the latter. The implicating pressures placed on social services, infrastructure, and the environment is enormous. The urban water cycle and water supply services are among the essential systems affected. Thus, the need to constantly improve the quality, availability, efficiency, and affordability of water in urbanised environments is paramount. The presence of performance measuring systems is among the tools utilised to attain these parameters and improve the quality of service in water companies.

This dissertation aims to attain an empirical understanding of benchmarking and the application of regulated performance indicators to determine the quality of service in water companies, over a 6-year evaluation period. The 14 Portuguese regulated performance indicators were applied to 24 water companies, and the performance of an identified water company; Be Water - Águas de Ourém was compared to the national and cluster performance.

The advantage and effectiveness of benchmarking and the use of regulated PIs was evident in this work. The PIs produced a measurable status quo and its evolution for all the multi-dimensional water companies, and the benchmarking offered an opportunity to identify the 'best practice' and a reference point to explore the characteristics, systems, and technologies used to promote operation and management productivity.

Keywords: Urbanisation, Benchmarking, Performance Indicators, Water supply services

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List of Abbreviations and Acronyms

AdP	Águas de Portugal
APA	Agência Portuguesa do Ambiente
APCER	Portuguese Association of certification
CMA	Catchment Management Agency
DWS	Department of Water and Sanitation
DWQ	Drinking Water Quality
ERSAR	Entidade Reguladora dos Serviços de Águas e Resíduos
INE	Instituto Nacional de Estatística
IWA	International Water Association
KPI	Key Performance Indicators
LCA	Life Cycle Assessment
MDG	Millennium Development Goals
MUA	Moderate Urban Area
NRW	Non-revenue Water
PEAASAR	Plano Estratégico de Abastecimento de Água e de Saneamento de Águas Residuais
PI	Performance Indicator
PRA	Predominantly Rural Area
PUA	Predominantly Urban Area
RPMS	Regulatory Performance Measurement System
RSA	Republic of South Africa
UWS	Urban Water System
UWSS	Urban Water Supply and Sanitation
WMA	Water Management Areas
WSA	Water Service Authorities
WSP	Water Service Providers
WWTP	Wastewater Treatment Plant

1. Introduction

1.1. Background

1.1.1. Population growth

Population is defined as a set of elements which a conclusion can be drawn about. The units used depend on the nature of the research topic and its objectives (*Defining and Framing the Population*, 2015).

'Demography is the study of human population including their composition, distributions, densities, growth and other characteristics' (Demena, 2005). It includes fertility, mortality, and migration. A census is one of the major sources of demographic data.

The 2021 Portuguese census is ongoing, and the results still not available. The information from the 2011 Portuguese census characterized the population with 10,555,853 inhabitants; a population density of 114 inhabitants per km^2; 4,079,577 families, living in 5,879,845 households and occupying 3,550,823 buildings (Mendes & Magalhães, 2011).

According to (Duarte & Gil, 2019), the demographic outlook for the population in Portugal seems unfavourable due to low birth rates, aging population and an increase in emigration. The average age in 2019 was recorded as 44.8 year from 33.9 in 1990's ; this may introduce challenges such as a reduction in the labour force, thus affecting economic growth and increasing the number of pensioners and healthcare expenditure. Furthermore, the balance between emigrant outflow and immigrant inflow has Portugal at a disadvantage as there are more individual with higher education departing (51,000) versus those arriving (24,000).

Population growth is anticipated to vary between industrialised countries (Portugal) and economically developing countries (South Africa).

In 2011, South Africa's census revealed the total geographical land areas as 1,220,813 km^2; distributed among the 9 provinces and occupied by 51,770,560 inhabitants; with the average age recorded as 25 which increased from 22 years in 1996 (Ngyende, 2011).

The birth rate is 0.65% ,and life expectancy (drastically influenced and reduced by the HIV/AIDS epidemic) is 57.6 (Kohler & Behrman, 2015).Immigration is centred around economic opportunities, particularly for miners from neighbouring countries (Shimeles, 2010).

It is evident that the demography in both Portugal and South Africa are divergent and influenced by different characteristics, although they do have one concept in common 'Urbanisation'; 65% of South Africa's population is urban (Kohler & Behrman, 2015), and similarly 65.75% of Portugal's population lives in urban areas and cities (O'Neill, 2021).

1.1.2. Urbanisation

Urbanisation is the process that transforms rural areas into urban settlements through the built environment. This complex socio-economic process alters the demographic and social structure (Montgomery et al., 2003), and the reclassification of areas from rural to urban or rural-urban migration (Buhaug & Urdal, 2013); is inspired by economic development, employment and educational opportunities (United Nations et al. 2018).

The effects of urban expansion, if unplanned may lead to rapid sprawl, which destroys natural landscapes and its biodiversity, through pollution, irregular production, and consumption patterns as well as environmental degradation. Thus, spatial planning is crucial (Angel et al., 2011).

More specifically, rapid population growth in urban areas leads to massive pressure placed on social services such as electricity, housing, water supply, health care and education. The environmental implications include water scarcity, contamination, and inadequate sanitation (Buhaug & Urdal, 2013). A study by Mikovits et. al., suggests that urban water infrastructure should be adapted through simulation to considering urban development and population growth (Mikovits et al., 2014).

1.1.3. Urban Water Cycle

Unfortunately, the effects of urbanisation are not limited to the water supply infrastructure, but the whole natural hydrological cycle. Figure 1.1 demonstrates the continuous transportation of water between waterbodies, through evaporation, transpiration (by plant), condensation, precipitation, soil infiltration and runoff; this process is referred to as the hydrological cycle (or water cycle) (U.S Geological Survey, 1984).

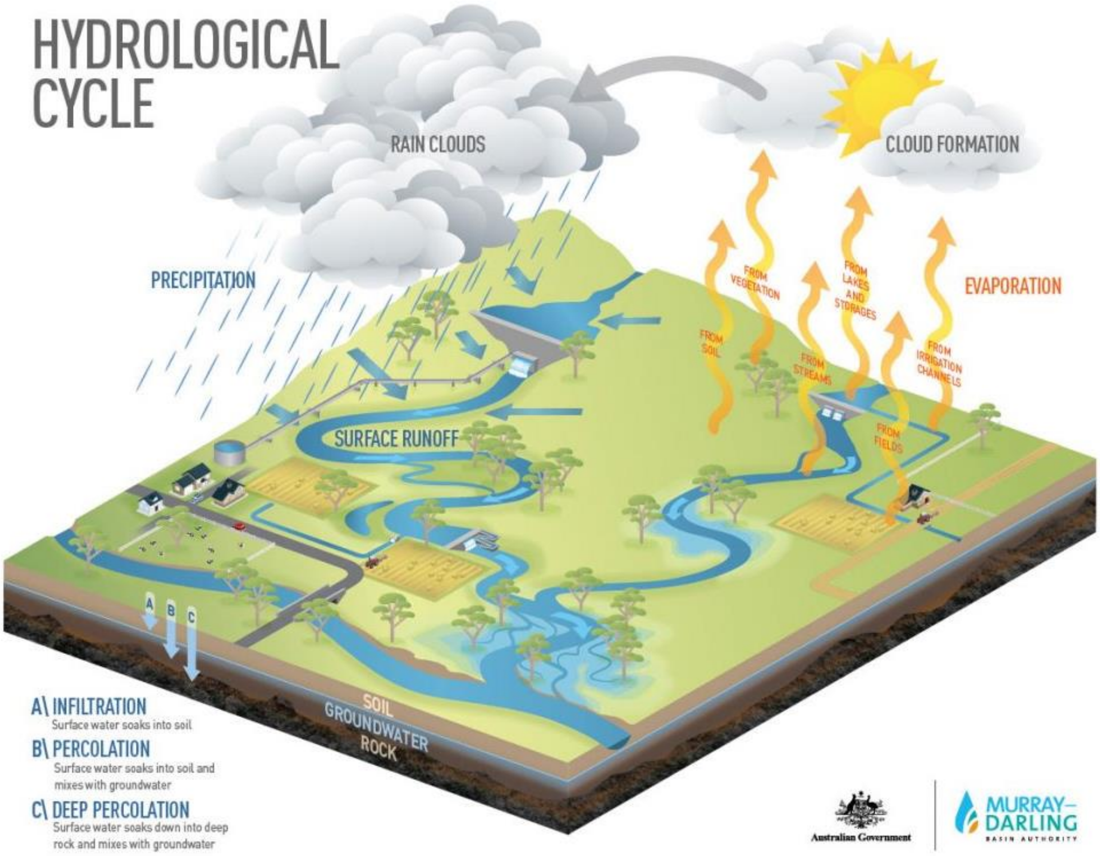


Figure 1.1 : Hydrological Cycle (Australian Environmental Education, 2019)

The main source of water in the urban water cycle is precipitation and the municipal water supply. The latter is largely dependent on the population served, commercial, institutional, and industrial activities within the area of concern. While on the other hand precipitation varies greatly in quantity, depending on local climate (Marsalek, 2014).

The municipal water supplied in urban areas originates from surface water (rivers, lakes, and reservoirs) or groundwater; this is referred to as raw water. It is transported to a treatment plant and thereafter to the distribution network to provide water to the different end users. The integrity of the entire infrastructure determines the quantity of water from the treatment plant to the end user's outlet tap. The systems' functionality and layout must have sufficient storage and pumping capacity to supply and maintain minimum pressures, under reasonable power requirements (Marsalek et al., 2006).

Figure 1.2 exemplifies the layout of the urban water cycle and the associated infrastructures.

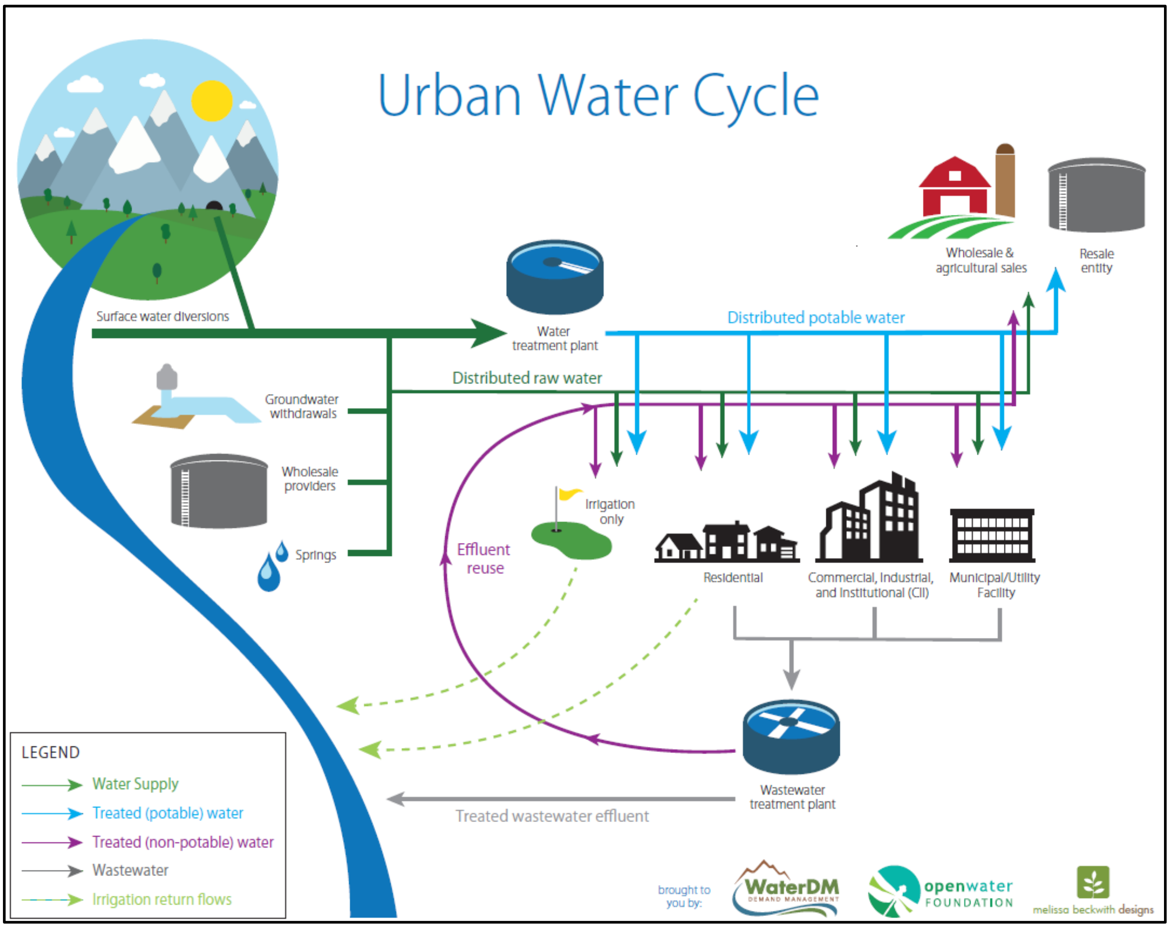


Figure 1.2 : Urban Water Cycle (WaterDM Demand Management, 2016)

Water supply and sewer treatment infrastructure is paramount in the transfer of large quantities of water and wastewater across the urban area (McGrane, 2016). Urban drainage is designed to prevent and minimize flooding and surface water ponding (Marsalek et al., 2006).

Simulation software's and mathematical models provide an opportunity to assess the hydrological impact and effectiveness of water supply and wastewater infrastructure, prior to and post construction (Peña-Guzmán et al., 2017).

1.1.4. Water Supply Services

Prehistorically the first well documented and successful water supply system existed in Italy, Rome around the first century AD (Mays, 2000). The system contained of approximately 420 km of pipework, covering distances up to 90 km and conveying almost 1 million m^3 of water per day (Trevor & Duckworth, 2002). Nowadays, water supply systems have achieved tremendous progress from their predecessor models.

The operation and maintenance of these systems require thorough knowledge and understanding of their components, geographical and physical information of the layout. Geographical Information System (GIS) is the preferred mapping system, due to its ability to create a database within a mapped area consisting of detailed information on the water supply system's physical structure and accompanying attributes (engineering, maintenance, and inspection information) (Ministry of Water and Energy, 2013).

Following water supply treatment (ground or surface), the integrity of the water distribution network is pivotal; composed of 3 areas: physical integrity, hydraulic integrity, and water quality integrity. The performance of each of these areas influences the others, e.g. If the physical integrity is compromised due to cracks in the pipe, this may result in increased friction losses (hydraulic integrity) and pollutants entering the network (water quality integrity) (van Zyl & Water Research Commission, 2014).

Figure 1.3 exemplifies the conventional water treatment method and Table 1.1 elaborates on the integrity areas of the water distribution system.

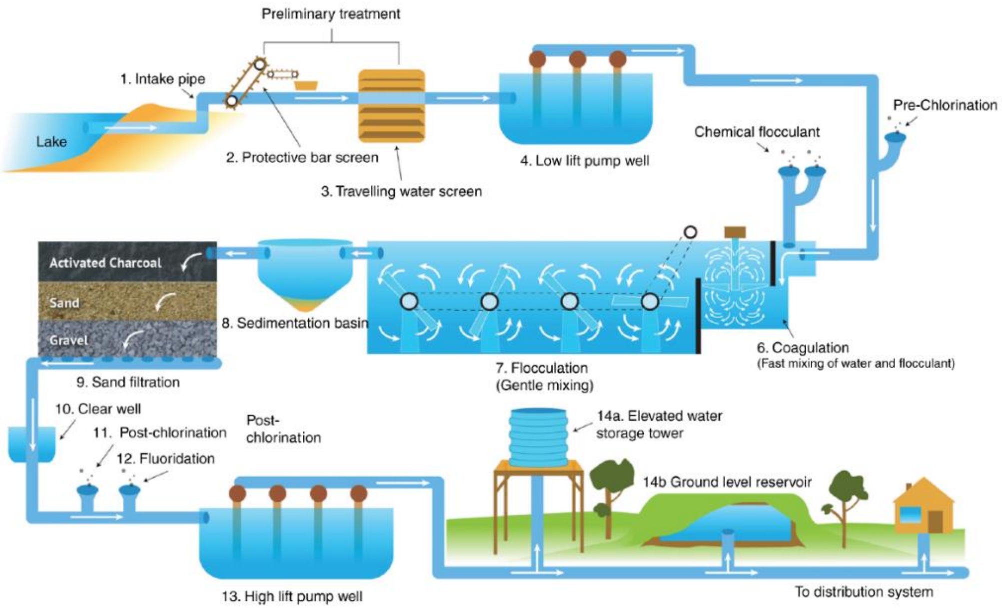


Figure 1.3: Schematic of conventional surface water treatment process (Harris et al., 2021)

Table 1.1 Water distribution system integrity

Group	Causes of loss in integrity	Consequences
Physical Integrity **"The ability to have correctly functioning components and maintain a physical barrier between the water in the network and the external environment"**	Design and construction factors – Design faults – Defective material – Missing or defective parts – Improper construction or repair – Improper use – Cross connection	• Unable to function as intended • Loss of water • Risk of contamination
	Physical factors – Excessive loads – Damage to components – Erosion – Exposure to sunlight – Cavitation	
	Chemical factors – Corrosion – Permeation	
Hydraulic Integrity **"The ability to meet all user demands while ensuring desirable pressures, velocities and water age in the system"**	Excessive demand	• Inability to satisfy consumer demand • Damage • Contamination • Accumulation of sediments • Depletion of disinfectant residuals
	Reduction in system capacity	
	Negative pressure	
	Pumping directly from the network	
	Pressure transients	
	Excessive pressures	
	Low velocities	
	Incorrect operational settings	
	Air in the system	
Water Quality Integrity **The water distribution systems' ability to deliver water of acceptable quality to its' users**	Contamination from external sources	• Health risk • Unacceptable aesthetics • Corrosion • Reduction in system capacity • Reduced effectivity of water meters
	Internal deterioration of water quality	

Source: Information extracted from (van Zyl & Water Research Commission, 2014)

Due to the dynamic and complex environment water supply systems exist in, accompanied by many influencing factors with competing objectives, it is necessary to enforce policies and procedures, but moreover apply benchmarking and performance indication system to guide operation and maintenance to achieve optimal results (van Zyl & Water Research Commission, 2014).

1.2.Problem statement

Rapid population growth and urbanisation have a large impact on the society, particularly in the water sector. The growing demand on already pressurised infrastructure is enormous and requires rapid solutions from an international perspective. This is a challenge experienced worldwide, although more vigorously in developing countries; due to institutional, economical, and financial shortcomings (Varis & Somlyódy, 1997).

The water sector in relation to urbanisation can be confronted by either scarcity or lack of water resources and its environmental impacts (Marsalek et al., 2006), or can also be affected by the lack of water supply systems, due to the deterioration of aging infrastructure or nonexistence of water supply systems (Varis & Somlyódy, 1997).

The quality, availability, efficiency, and affordability of water in urbanised environments are amongst the many parameters which constantly require re-adaptation and advancement in operation and management due to the ever-increasing population and changing environmental dynamics.

In the last two decades, interest has grown in the implementation of tools and management techniques to facilitate improvement in the performance of companies in the water and wastewater sector (Rautu et al. 2017). Specific or holistic performance indicators are the main quantitative management tool utilised to assess the serviceability of individual water companies and benchmarking these results encourages performance improvement, creates communication opportunities to seek the best practice and supports funding application to the government. (European Environmental Agency, 2014; González Villarreal & Lartigue, 2017);

1.3. Global and specific objectives

According to the United Nations World Water Development Report (United Nations, 2015); freshwater resources are encountering pressure in relation to providing for the three dimensions of sustainable development (social, economic, and environmental) for the growing world population.

This is the case particularly for slum populations in urban areas of the developing world, without access to water and sanitation. With some of the local and national governments unable (or unwilling) to provide adequate water and sanitation facilities.

The vision for 2050 is to make safe and sufficient water available to meet a populations basic need and maintain a healthy lifestyle through reliable and affordable water supply and sanitation services (United Nations, 2015).

Access to safe drinking water is the cornerstone of any healthy population, hence from 1981 to 1990, the goal from the United Nations International Drinking Water Supply and Sanitation was to provide safe drinking water for all (Mays, 2000).

The objective of this dissertation is to attain an empirical understanding of the application of performance indicators to evaluate and monitor the effectiveness and efficiency of water supply companies in Portugal, leading to opportunities for improvement in the quality of service.

Furthermore, through benchmarking the performance amongst water companies; a status quo can be established, and the best practice identified. This will as a result, exhibit the characteristics and technologies that promote operation and management productivity in reference to the guidelines outlined in the relative regulations.

The methodology considered aims at attaining a practical understanding of benchmarking through the application of performance indicators amongst Portuguese water companies, possessing similar characteristics, as well as assessing the evolution of their performances.

1.4.Document structure

Chapter 1 introduces the concept of population growth and urbanisation; the implications and effects it has on the environment, particularly the urban water cycle as well as the overall operation of water supply services. It further describes the objectives of this report and exhibits the structure and overview to facilitate comprehension.

Chapter 2 explores the concept of benchmarking and exemplifies the performance indicators used in the South African and Portuguese water sector. It also assesses the national evolution of the identified performance indicators, and an additional an in-depth evaluation of Portugal’s non-revenue water (NRW) performance indicator.

Chapter 3 is based on a case study of Be Water - Águas de Ourém, a water supply company located in the centre region of Portugal. The investigation examines the performance of this company against the 14 performance indicators specified by ERSAR (the Portuguese water regulator). This is done over a 6-year evaluation period to assess the evolution within each performance indicator.

Furthermore, the results are benchmarked to the national average as well as the cluster average, which is inclusive of 23 other water supply companies located in the same moderately urban areas, in the centre region.

Chapter 4 presents a discussion of the results from both the South African and Portuguese implemented performance indicators, and the effectiveness of benchmarking. The discussion also includes the identification of significant performance indicators in the individual developing and developed countries respectively. Recommendations and future work, building on the content of this thesis is presented.

2. Performance Indicators and Benchmarking

In the last two decades, management techniques have been explored in the water supply sector to improve company performance. One of the main techniques designed to advance performance through systematic research and adaptation of the ‘best practice’ is Benchmarking. This management tool is used and recommended by the International Water Association (IWA) (ERSAR, 2021a).

The other tools utilised to track the systems performance are performance indicators (Ganjidoost et al., 2018), developed by a combined effort from researchers, legislators, and industry practitioners.

The importance of Performance Monitoring is outlined in a report by (Palestine Water Authority, 2011); expounding on the interests of the different stakeholders; commencing with regulators and their ability to define targets and monitor compliance of the service providers through the application of the monitoring systems.

Secondly service providers, and their propensity to measure and understand the performance of various departments with the aim of developing methods of improvement and adapting best practices through benchmarking.

Policy makers benefit through performance monitoring systems, as they assist in formulating and implementing policies in the water sector, allocating investment and resources, as well as developing updated regulating tools and standards. The best interest of the end user is also considered through the quality of service of performance indicators related to tariffs and response to customer suggestions.

According to (Independent Pricing and Regulatory Tribunal, 2018), these measures assess change and performance against set targets, navigating the direction to be taken to achieve the desired outcome based on accurate and aligned data.

A comparison between lag indicators (out-put related historical measures) and lead indicators (in-put related predictive measures) is essential.

2.1. Performance Measurement Concept

The availability and affordability of water is heavily dependent on water supply system performance, which affects the economic, environmental, and social spheres of sustainable development (Vilanova et al., 2015).

The efficiency and effectiveness by which a water company conducts its services and the process of quantifying these actions is referred to as performance measurements. In this context ‘efficiency’ refers to the measure of how practical the company uses its resources to provide services and ‘effectiveness ‘refers to the extent to which the requirements of water users are met (Neely et al., 2005).

Performance measurements can be examined individually, as a set, or in relation to the environment they operate in (Neely et al., 2005). The objective is to monitor performance trends; better inform decision makers; indicate priorities and actions; verify the effectiveness of optimized measures and benchmark performance with other counterparts (Vilanova et al., 2015).

The importance of performance measurements was exhibited in a study from India by (Jaladhi et al., 2016), whereby the absence of performance assessment systems (measuring and monitoring) in the Urban Water Supply and Sanitation (UWSS) services led to the misallocation of resources and emanated in the deterioration of the level of service and performance over time.

2.2.Benchmarking Concept

Benchmarking is a valuable tool that promotes quality and excellence in any day-to-day public or private organisation, and this has been the case since the early 1900s. This business tactic can be applied in goal setting, process improvement, planning and problem solving.

Benchmarking can be applied through adaptation and systematically improving the company's performance and operation based on its' own processes or the performance of other successful companies (best in practice /most effective) (Gonzalez & Salman, 2002). Depending on the comparison and what the item/system is being compared against, there are different types of benchmarking; some of which are exemplified in Table 2.1.

Table 2.1 Benchmarking types

Types	Definitions
Performance benchmarking	The comparison of performance measures for the purpose of determining the efficiency of a company compared to another.
Process benchmarking	When the company's methods and processes are compared with the aim to improve them.
Strategic benchmarking	This is conducted when the company attempts to change their strategic direction, by also evaluating similar competing company strategies.
Internal benchmarking	Comparisons made between departments/ divisions within the same company.
Competitive benchmarking	This is the performance and result comparison against the "best" competing.
Functional benchmarking	The comparison of technology/process within one's industry with the aim of becoming the best.
Generic benchmarking	Best process comparison, irrespective of the industry.

Source: (Bhutta & Huq, 1999)

Benchmarking is an ongoing process that continuously adapts to effectively serve the company's customers with relevant, optimised, and efficient solutions. It does come at a cost (e.g., travel expenses and overtime worked by employees), although if carefully planned and executed in narrow, and defined stages; the cost can be controlled and kept at a minimum. Some of the misconceptions about benchmarking are (Bhutta & Huq, 1999);

- Benchmarking is a onetime project.
- Benchmarking is too expensive.
- Benchmarking gives too much information to one's competitors.

Successfully improved performance requires constant performance evaluation based of set goals and 'best practice' standards, thus benchmarking cannot be viewed as a onetime project. The cost can be managed and employees providing information should exercise caution not to give out core company data.

2.2.1. Benchmarking in Water Services

Benchmarking in water services requires the analysis of a set of PIs to obtain a meaningful comparison of the multi-dimensional regulated activities (Henriques et al., 2020). The two commonly used methods for benchmarking include metric benchmarking (overall performance compared with other companies) and process benchmarking (identifying internal procedures to be improve). Table 2.2 exhibits the application areas for each method (Seppälä, 2015).

Table 2.2: Main methods of benchmarking utilised in Water Services

Methods	Application areas
Metric benchmarking	Service coverage, Water production and consumption, non-revenue water, Metering, Network performance, Operating costs and staff, Quality of service, Affordability, Billing and collections, financial performance, Process indicators, Assets
Process benchmarking	Customer service, Billing and revenue collection, Debt management, Capital procurement, Sewage treatment plants, Renovation of sewers, Maintenance, Laboratories, Research and development, Information systems, Energy management, Asset management

Source: (Seppälä, 2015)

When benchmarking water companies, the basic operating conditions need to be recognised and this is done to achieve relevant and comparable results. Elements such as topography, geology, hydrology, scale of production, network age, customer density and income are essential as these factors are beyond the control of the present management team (S. v Berg, 2020).

The supervision of operations' activities independently of the water company and ensuring overall quality of service (QoS) is the responsibility of the regulator (Henriques et al., 2020). Hence clearly defining the QoS targets as public policy is essential (Melo Baptista, 2018). Table 2.3 exemplifies the range of potential targets for QoS.

Table 2.3: Potential targets for Quality of Service

Item	Defined targets
Quality of Service	Quality of Service based on Performance Indicators Annual assessment of Quality of service Annual assessment of the water companies Annual benchmarking between water companies Assessment of the evolution for each indicator Promoting water Quality Assessment of the evolution of the quality

Source:(Melo Baptista, 2018)

In Europe, water utilities have used benchmarking either voluntarily or due to regulatory requirements for more than 25 years, and since the 1990's these activities were developed in a more institutionalised manner. Table 2.4 illustrates the benchmarking initiatives found in European countries (EurEau, 2015).

Table 2.4: Benchmarking Initiatives in Europe

Name	Scope	Created	Short description
Vewin benchmark Reflections on performance	Netherlands	1997	It started as an initiative of the Dutch drinking water companies. The benchmarking is now part of the transparency obligations under the Drinking Water Act; executed by the supervising government. All Dutch drinking water companies take part.
BDEW (German Association of Energy and Water Industries) and DVGW (German Technical and Scientific Association for Gas and Water)	German	2002	BDEW and DVGW supports various benchmarking projects and conducts the development of systems in Germany.
Entidade Reguladora dos Serviços de Águas e Resíduos (ERSAR) **The Water and waste Services Regulation Authority in Portugal**	Portugal	2009	ERSAR is in charge of regulating public water supply services, urban wastewater management and municipal waste management services.
OFWAT	England and Wales	1989	OFWAT publishes a wide range of data about companies' performance. The water companies also publish benchmarking data annually on a voluntary basis.
Water Industry Commission for Scotland (WICS)	Scotland	2002	The regulator WICS publishes benchmarking information about Scottish Water performance including cost, customer service and leakage.
Observatoire National des Services D'eau et d'Assainissement **National observatory on water & sanitation services by the French national agency for water (Onema)**	France	2006	The national observatory on water & sanitation services provides access to information and data on the public drinking-water and sanitation services, their organisation, price(s) and performance levels. The data is provided on a voluntary basis.
DANVA Benchmarking	Denmark	2002	Majority of Danish water and wastewater companies take part in the benchmarking initiative for the purpose of measuring and enhancing performance.
FIWA benchmarking (VENLA)	Finland	2006	FIWA is a voluntary benchmarking system with member utilities.

Source: (EurEau, 2015)

Globally there are several successful benchmarking initiatives utilizing performance indicators as the main tool. These are illustrated in Table 2.5.

Table 2.5 : International Benchmarking Initiatives

Name	Scope	Created	Short description
IWA Benchmarking & performance Assessment Specialist Group (BPA SG)	Worldwide	2010	This is a forum for networking opportunities, discussing, promoting, and improving all activities related to performance assessment and benchmarking of water services
The European Benchmarking Corporation (EBC)	Europe	2004	This not-for-profit benchmarking initiative aims to facilitate water utilities in improving their performance and raising transparency
ISO (International Organisation for Standardization) **ISO/TC 224 Service activities relating to drinking water supply systems and wastewater systems – Quality criteria of the service and performance indicators**	Worldwide	2007	Standardisation might help water services to organise Benchmarking between utilities to improve their performance and set confidence with Stakeholders by developing an appropriate communication.
The International Benchmarking Network for Water and Sanitation utilities (IBNET)	Worldwide	Late 1990's	This is an initiative to encourage water and sanitation utilities to compile and share a set of core cost and PI's, and thus meet the needs of the various stakeholders

Source: (EurEau, 2015)

As majority of water utilities worldwide are natural monopolies, national regulators are essential. A regulatory authority with a solid organisational structure and resources, clear public policies on water services and requirements from service providers is what every country should strive to establish. Furthermore, in addition to the outlined benchmarking benefits, regulators can ensure user protection, particularly if thoroughly researched and implemented.

2.3. Overview of the Water Service Performance in South Africa and Portugal

2.3.1. A case study from a developing country (South Africa)

2.3.1.1. Introduction

Pre-1994 the apartheid era left an impact in South Africa that is still difficult to ignore in the different elements of the water sector and other sectors. The Native Land Act of 1913 introduced restrictions which lead to poverty, poor potable water access, illiteracy, and malnutrition amongst black South Africans. Post 1994, the democratic government´s priority was to address the highly unequal access to water and other services to meet the minimum basic needs of the population and reconstruct the social & economic base of the country (Madigele, 2018).

The above was attained through the Water Services Act (RSA, 1997) which was aimed at ensuring that all citizens have access to basic water supply and sanitation services, and the National Water Act (RSA, 1998) which established a foundation for management of water resources on a catchment basis (for sustainability, equity, and efficiency) (Mokgope et al., 2001).

These two Acts are the fundamentals in the regulatory framework used by the Department of Water and Sanitation (DWS) to provide governance and develop & implement policies and legislation in the South African water sector (Beck et al., 2016; Masindi & Dunker, 2016).The need to speed up the provision of safe and acceptable household sanitation facilities and water supply was influenced by the outbreak of cholera in 2000 (Department of water and forestry, 2001).

This led to the national government implementing the Free Basic Water policy in 2001. After acknowledging the ongoing affordability and capacity challenges across different municipalities (the policy was revised in 2007) (Beck et al., 2016).

In 2000, South Africa was among the countries from the global community who pledged to attain the eight Millennium Development Goals (MDGs), and meet specific targets aimed at eradicating extreme poverty by 2015 (United Nations, 2000).The MDG (Target 7C; Ensuring Environmental sustainability) in relation to water, anticipated halving the number of people without sustainable access to safe drinking water and basic sanitation services in both urban and rural areas. South Africa had already set goals related to water access and infrastructure in 1994 (Parliamentary Monitoring Group, 2012) , hence achieving these targets in 2005 and 2008 respectively (Masindi & Dunker, 2016).

Table 2.6 exemplifies the list of all the policies and legislation that provide structure and a framework to guide the Department of Water and Sanitation in governing and Table 2.7 displays the institutional framework in the South African water sector.

Table 2.6 : Policies and Legislation governing the Department of Water and Sanitation (DWS)

Legislation	Description
Water Service Policy, (White Paper) 1994	Prioritises the backlogs in the country's water service and institutions and mechanisms needed to remedy the backlogs.
Republic of South Africa Constitution Act 108 of 1996	Establishes a human's right dimension for access to adequate and sustainable services (including water supply) and dignify the Bill of Right.
National Water Act 36 of 1998	Establish institutions to ensure that water resources are conserved, protected, developed, used, and managed in a sustainable manner.
Water Services Act 108 of 1997	Set a national framework that promotes effective water resource management and conservation, that will enable access to basic water supply and sanitation; improving the quality of life and averting a harmful environment to the health and wellbeing of the population.
The Free Basic Services Policy of 2001	Entitles households to free basic services; defined as 6 kilolitres of water per month and free basic sanitation services (in the form of Ventilated Improved Pit toilet, and others. The cost to be met by Municipality's "equitable share" of national revenue.
Strategic Framework for Water Services (2003)	It sets goals and defines responsibilities for Water Services Authorities (WSA) and Water Services Providers (WSP).
National Water Policy Review (2013)	Aims to address water challenges experienced by DWS; regarding improved access, efficiency, equity, and sustainability.
National Water Resources Strategy Second edition (2013)	Informs and encourages achieving sustainability of water resources, their security, and national priorities.
National Sanitation Policy Draft (2016)	Provides measures to be taken to provide citizens with access to basic sanitation services, as well as encourages good hygiene and effective management of sanitation facilities.

Source: (Folifac, 2007; Masindi & Dunker, 2016)

Table 2.7 : The Institutional Framework in the South African water sector

Level	Entity	Abr.	Description / Responsibility
National	Department of Water and Sanitation	DWS	Develops and implements policy and strategies that governs the water sector. Regulates and monitors the performance of the sector. Responsible for large water resource infrastructure [1]
Regional	Catchment Management Agencies	CMA	Manages water resources
	Water Boards		Manages bulk water and wastewater distribution
Local	Municipalities /Water Service Authorities	WSA	Responsible for the provision of water services (water supply and sanitation)
	Water Service Providers	WSP	Provides water and/ or sanitation services for municipalities & may also perform contractual duties, as specified by WSA (may be public, private, mixed, or governed by the municipality itself).

[1] The management of water resources has been decentralised in RSA, therefore Catchment management agencies (CMA), within water managements Areas (WMA) were established

Source: (Beck et al., 2016; Masindi & Dunker, 2016)

According to (Carden & Armitage, 2013), there have been several benchmarking initiatives implemented in the South African water sector in terms of regulatory performance measurements as well as operational business performance measurements for municipal water services. The initiatives under the Department of Water and Sanitation (DWS) were implemented as a National Water Service Regulation Strategy aimed at assessing the poor performance for services and delivery of infrastructure from municipalities and water service authorities (WSAs). They included three priority programs.

i. The Regulatory Performance Measurement System (RPMS) – A centralised regulatory system to address the performance and compliance in municipalities.
ii. The 'Blue Drop' – A national drinking water quality regulatory initiative.
iii. The 'Green drop' – A national effluent quality regulation initiative.

The RPMS was designed to measure and monitor the performance of individual WSA according to the 11 Key Performance Indicator (KPI) areas indicated in Table 2.8.

Table 2.8 Key Performance indicators from the RPMS

Indicator	Description
KPI 1	Access to water supply
KPI 2	Access to sanitation
KPI 3	Access to free basic water
KPI 4	Access to free basic sanitation
KPI 5	Drinking water quality management
KPI 6	Wastewater quality management
KPI 7	Customer service quality
KPI 8	Institutional effectiveness
KPI 9	Financial performance
KPI 10	Strategic asset management
KPI 11	Water use efficiency

Source:(Selowa, 2018)

After identifying a gap in the RPMS from the leak of regulation on the entire water value chain (raw water, bulk water, and retail water), additional capacity was sourced in 2014, through the economic and social regulation Chief Directorate. The RPMS resulted in improvements, although significant challenges in achieving its goals were experienced due to (Selowa, 2018):

i. Lack of legislative backing for implementation of punitive measures
ii. Lack of capacity in implementation of the RPMS in DWS
iii. Lack of prioritisation of the programme by DWS
iv. Lack of prioritisation of the programme by WSAs
v. Lack of capacity in the regulated institutions

Contrarily, the 2008 'Blue drop' initiative aimed to monitor compliance of the quality of drinking water provided by the country's municipalities, experienced its first significant improvements in 2011 (Creamer Media, 2012). The incentive-based programme evaluates municipalities using the criteria in Table 2.9; where there are 5 categories of assessment, each contributing to the final municipal Blue Drop score.

Table 2.9 : Blue Drop Certification criteria

Group	Weight [%]	Performance Areas	Weight [%]
Water safety Planning	35	Water safety planning process	10
		Risk assessment	30
		Risk-based monitoring programme	25
		Credibility of DWQ data	20
		Incident management	15
			……. / [100]
DWQ process management & control	10	Works' classification compliance	15
		Process control registration compliance	50
		Availability of water treatment works logbook	35
			……. / [100]
Drinking Water Quality Compliance	30	DWQ compliance (Microbiological)	50
		DWQ Compliance (Chemical)	40
		Risk refined Compliance	5
		Operational Efficiency Index	5
			……. / [100]
Management, Accountability, & Local Regulation	10	Management Commitment	40
		Publication of Performance	30
		Service Level agreement/ Performance Agreement	15
		Submission of DWQ data	15
			……. / [100]
Asset Management	15	Annual Process Audit	20
		Asset Register	15
		Availability & Competence of Maintenance Team	15
		Operations & Maintenance manual	15
		Operations & maintenance Budget and expenditure	20
		Design Capacity vs. Operation capacity	15
			……. / [100]
Municipal Blue Drop Score	**……. / [100]**		

Source: (Department of Water Affairs, 2012)

The Blue Drop certification is the highest drinking water quality classification, amongst 5 lower classifications. It is achieved when a municipality attains 95% score. The assessment is conducted by a team consisting of a qualified drinking water quality professional (leader), 2-4 inspectors (assessors) and a leaner assessor (Department of Water Affairs, 2012).

2.3.1.2. National evolution of performance indicator from 2009 - 2014

The data used to conduct this analysis was collected from the Blue Drop Reports published by the Department of Water and Sanitation. Table 2.10 provides a consolidated and indicative overview of the national performance and results of the water quality management programme, with the core objective of safeguarding and improving the quality of life for South Africans.

Table 2.10 : Evolution of the Blue Drop Program

Performance Category		Unit	[a] 2014	[b] 2013	[a] 2012	[c] 2011	[c] 2010	[c] 2009
Number of municipalities assessed		Nr.	152	152	153	162	153	107
Number of water supply systems assessed		Nr.	1036	1009	931	914	787	402
Number of Blue Drop scores ≥ 50%		Nr.	-	-	-	536	370	183
		[%]	-	-	-	58.7	47	45.5
Number of Blue Drop scores < 50%		Nr.	-	-	-	378	417	219
		[%]	-	-	-	41.3	53	54
Number of Blue Drop awards		Nr.	44	-	98	66	38	25
National Blue Drop Score		**[%]**	**79.6**	**-**	**87.6**	**72.9**	**67.2**	**51.4**

Source: [a] (Department of Water and Sanitation, 2014); [b](Department of Water and Sanitation, 2013); [c](Department of Water Affairs, 2011);

2.3.2. A case study from a developed country (Portugal)

2.3.2.1 Introduction

Portugal’s water supply services are organised as bulk and retail operations recognised as Economic Service of General interest under the Law of Essential Public Services. The responsibility for these services is generally shared by the state and municipalities. In 1993 the public holding Águas de Portugal (AdP) was established to link central government investment with those of municipalities and the shared capital was 51% to 49% respectively (Martins & Fortunato, 2016).

The Portuguese Strategic Plan of Water and Wastewater Sewerage (known as PEAASAR) indicated its aim of prioritising the constructions of bulk infrastructure between 2000 – 2006. As a result, this induced integrated solutions that created 13 multi-municipal and 7 inter-municipal systems.

In 2006 a first revision of the strategic plan known as PEAASAR II 2007-2013 was formulated and focused on retail services in relation to improving efficiency and establishing guidelines and financial models for tariff policies. In 2014 the Portuguese Government presented a second revision of the strategic plan for the water industry with the aim to achieve territorial and social cohesion, sustainability, and increased levels of efficiency from 2014 to 2020, known as PENSAAR 2020.(Martins & Fortunato, 2016).

Presently a third revision of the Portuguese Strategic Plan of Water and Wastewater Sewerage for the next decade is ongoing (known as PENSAARP 2030). The new policies for Urban Water Cycle Management includes rainwater management, Water Circular Economy, diversification of water sources, services decarbonization and digital transformation.

According to the last Annual Report of the ERSAR – Portuguese Water and Waste Services Regulation Authority (ERSAR, 2021a) , the water supply service in Portugal has drastically evolved in the last two decades. This was achieved through substantial investment from the Water Companies in infrastructures and human resources – through self-financing and European Funds.

Bulk water services are generally provided by State owned companies, while municipalities are responsible for retail operation (Marques et al., 2005). At a retail level, the water supply industry is very fragmented with approximately one service provider per municipality (308 Portuguese municipalities), thus resulting in small and focused utilities within each municipality (Martins & Fortunato, 2016).

The methodology for evaluating the quality of water supply service provided to users is defined by ERSAR and updated annually. Table 2.11 below outlines the methodology applied and sequence followed in the evaluation process of efficiency and effectiveness in the activities of management entities (ERSAR, 2021a).

Table 2.11 : The implementation phases of the quality-of-service assessment

Description	Responsibility of Water Company	Responsibility of ERSAR
Provision of data by the water company	●	
Validation of data by ERSAR for all the water companies		●
Data processing and interpretation of results by the ERSAR for each water company		●
Data processing and interpretation of results by the ERSAR for all water companies		●
Publication and dissemination of the annual evaluation report of water service quality		●

Source: (ERSAR, 2021a)

Nowadays Portugal uses 14 performance indicators to measure the water supply quality in terms of efficiency and effectiveness of the service provided by the water companies. Table 2.12 illustrates the performance indicators.

Table 2.12 : Water Supply performance indicators (ERSAR, 2020)

Group	Description	Code	Performance indicator	Unit
Adequacy of the user interface	Accessibility of the service to users	AA 01	Physical accessibility of the service	%
		AA 02	Economic accessibility of the service	%
	Quality of service provided to users	AA 03	Occurrence of water supply failures	[no/(1000 branches·year)]
		AA 04	Safe water	%
		AA 05	Response to complaints and suggestions	%
Service management sustainability	Economic sustainability	AA 06	Spending coverage	%
		AA 07	Service subscription	%
		AA 08	Non-revenue water	%
	Infrastructure sustainability	AA 09	Pipeline rehabilitation	(%/year)
		AA 10	Damage to pipes	[no/(100 km·year)]
	Physical productivity of human resources	AA 11	Adequacy of human resources	m^3/(km·day)]
Environmental sustainability	Efficiency in the use of environmental resources	AA 12	Actual water losses	[m^3/(km·day)] [l/(branch·day)]
		AA 13	Energy efficiency of pumping installations	[kWh/(m^3·100 m)]
	Efficiency in preventing pollution	AA 14	Proper handling of treatment sludge	%

Source: (ERSAR, 2020)

2.3.2.2 National evolution of performance indicators from 2015 – 2020.

In preparation for the analysis, data was collected from the annual ERSAR publication regarding the national performance of the 14 indicators prioritised by Portugal. Table 2.13 captures the national evolution of the 14 indicators; including the percentage difference within individual indicators estimated by Formula (3.1).

Table 2.14 provides an indicative overview of the performance indicators over the last 6-year evaluation period, including an exposition of the results.

$$Percentage\ Difference = \left| \frac{Lowest\ Value - Highest\ Value}{(Lowest\ Value + Highest\ Value)/2} \right| \times 100 \qquad (3.1)$$

Table 2.13 : Evolution of performance indicators in Portugal from 2015 - 2020

Code		[a] 2020	[b] 2019	[c] 2018	[d] 2017	[e] 2016	[f] 2015	Unit	Percentage difference	Consolidated % Difference
AA 01	PUA	99	99	99	99	100	100	%	1.0	1.4
	MUA	95	95	95	95	95	94		1.1	
	PRA	93	92	92	92	92	91		2.2	
AA 02		0.36	0.37	0.38	0.4	0.4	0.4	%	10.5	10.5
AA 03		0.7	0.8	0.9	0.8	0.9	0.9	[no/ (1000 branches·year)]	25.0	25.0
AA 04		98.79	98.76	98.9	98.88	98.78	98.63	%	0.3	0.3
AA 05		92	92	90	89	84	89	%	9.1	9.1
AA 06		109	109	109	108	107	105	%	3.7	3.7
AA 07		88.2	87.6	87	86.5	85.8	85.8	%	2.8	2.8
AA 08		28.8	29.4	30.2	29,8	29.8	30.1	%	4.7	4.7
AA 09		0.5	0.5	0.6	0.6	0.8	0.6	(%/year)	46.2	46.2
AA 10		38	38	42	40	41	37	[no/ (100 km·year)]	12.7	12.7
AA 11	PUA	3.6	3.7	3.6	3.6	3.7	3.6	m3/(km·day)]	2.7	4.4
	MUA	2	2	2	2.1	2	2.1		4.9	
	PRA	1.7	1.7	1.7	1.7	1.7	1.8		5.7	
AA 12		125	128	137	126	126	127	[l/(branch·day)]	9.2	9.2
		3	2.9	4	3.6	2.3	2.1	[m3/(km·day)]	62.3	62.3
AA 13		0.47	0.47	0.48	0.49	0.5	0.48	[kWh/(m3·100 m)]	6.2	6.2
AA 14		97	98	98	97	95	99	%	4.1	4.1

Observation: PUA – Predominantly Urban Area; MUA – Moderate Urban Area; PRA – Predominant Rural Area

Source : [a] (ERSAR, 2021a); [b](ERSAR, 2019); [c](ERSAR, 2018); [d](ERSAR, 2017); [e](ERSAR, 2016b); [f](ERSAR, 2016a)

Table 2.14 : Analysis of the last 6-year evolution of the performance indicators

Code		Annual report						Comment
		(a) 2020	(b) 2019	(c) 2018	(d) 2017	(e) 2016	(f) 2015	
AA 01	**PUA**	Good	Good	Good	Good	Good	Good	A 1% decrease was experienced between 2016 - 2017.
	MUA	Good	Good	Good	Good	Good	Good	The results were constant over the 6-years evaluation period
	PRA	Good	Good	Good	Good	Good	Good	A 1% increase was experienced between 2019-2020
AA 02		Good	Good	Good	Good	Good	Good	Between 2015 - 2017, the results were constant, although thereafter a continual decrease was recorded, amounting to a total of 10.5%.
AA 03		Good	Good	Good	Good	Good	Good	There was 25% reduction in the occurrence of water supply failures between 2015 - 2020. This is the 3rd largest improvement among other indicators.
AA 04		Good	Good	Good	Good	Good	Good	The results for this indicator pertaining to water quality have remained constant at 98.7% with slight fluctuation.
AA 05		Average	Average	Average	Average	Unsatisfactory	Average	Response to complaints and suggestions have seen a 9.1% increase gradually over the 6-years evaluation period.
AA 06		Good	Good	Good	Good	Good	Good	This indicator has only experienced a 3.7% variation over the 6-year evaluation period. These are excellent results.
AA 07		Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory	This indicator has increased by 2.8%, commencing at 85.8% in 2015 to 88.2% in 2020. To improve the customers' quality of life, opportunities within this indicator should be explored.
AA 08		Average	Average	Unsatisfactory	Average	Average	Unsatisfactory	The highest recorded non-revenue water was in 2018 at a total of 30.2%. This value has from that point decreased to 28.8% in 2020. -There are still high percentages of NRW from some utilities, thus improvement & reinforcement is required.
AA 09		Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory	Average	Unsatisfactory	This indicator is governed by several factors, from types of leaks, age of infrastructure and the utility's asset management programs. There was a decrease of 46.2% over the evaluation period. Rehabilitation programs are essential to assess opportunities for improvement.
AA 10		Average	Average	Average	Average	Average	Average	This indicator experienced a 12.7% gradual decrease over the evaluation period. An increase in pipeline rehabilitation will in turn contribute to a reduction in the number of failures.
AA 11	**PUA**	Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory	PUA – The values are above the acceptable range; it is necessary that water utilities seek to permanently designate human resources.
	MUA	Good	Good	Good	Good	Good	Good	MUA – The values are within the good quality range, with a slight variation of 4.9%.
	PRA	Average	Average	Average	Average	Average	Average	PRA - This indicator has remained constant over the evaluation period.
AA 12		Average	Average	Average	Average	Average	Average	This was the best performing indicator with a 62.3% percentile difference in (m^3/km·day) . The year 2018 had the most losses, although prior and post 2018 the losses were lower.
		Good	Average	Average	Average	Good	Good	The percentile difference in (l/branch·day) was 9.2 %.
AA 13		Average	Average	Average	Average	Average	Average	This indicator has gradually decreased over the evaluation period with a total of 6.2%.
AA 14		Average	Average	Average	Average	Average	Average	Proper handling of treatment sludge has improved by 4.1%; from 95% in 2015 to 97% in 2020.

Good Quality of service | Average Quality of service | Unsatisfactory Quality of service

Source: [a] (ERSAR, 2021a); [b](ERSAR, 2019); [c](ERSAR, 2018); [d](ERSAR, 2017); [e](ERSAR, 2016b); [f](ERSAR, 2016a)

2.3.3. Non-revenue water (NRW) performance indicator

There are several Performance Indicators (PI) available in the water sector, including the PIs published by the International Water Association (IWA), which range from simple network operational management to detailed functions and operational practice (Kanakoudis & Tsitsifli, 2010). However, due to urbanization, water utilities are faced with chronic water losses worldwide (Liemberger & Wyatt, 2019), resulting in a high-water production and delivery cost (González-Gómez et al., 2012a).

According to (Kingdom, Liemberger, & Philippe, 2006) the volume of NRW worldwide in urban supply systems annually is estimated at more than 32 billion cubic meters of treated water, physically leaking and 16 billion cubic meters delivered to customers for zero revenue. The total financial losses from utilities around the world is estimated at US $ 14 billion.

There are several characteristics that influence the volume of water lost, which include the pipe network, operational practices applied by the water utility and the type of technology and expertise utilised (Farley & Trow, 2003).Exploration and understanding of the characteristics and factors affecting water losses, and the challenges associated with its reduction is crucial in developing a solid and effective management strategy (C. van den Berg, 2015a).

The overall reduction of NRW is beneficial in terms of environmental, social, and economical sustainability. Amongst the water savings benefits, the reduction of NRW would improve water supply services and reliability, improve water quality, decrease energy consumption, save resources, and delay water capacity expansion projects. (Liemberger and Wyatt, 2019).

The basic concept of NRW is extracted from the International Water Association (IWA) standard for Water balance (Güngör-Demirci et al., 2018), and is exemplified in Figure 2.1. It is defined as the difference between the volume of water at entry point of the network and the volume billed to the end user (Kingdom et al. 2006).

Water at entry point of System	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non- Revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Apparent Losses	Unauthorised consumption	
			Metering inaccuracies	
		Real Losses	Leakage and transmission and/or distribution mains	
			Leakage and overflows at utility's storage tanks	
			Leakage on service connections up to point of customer metering	

Figure 2.1 : Water Balance (Kanakoudis & Tsitsifli, 2010)

2.3.3.1. Objective and scope

This section aims to examine the relationship between the four types of NRW indicators namely, NRW as a percentage, NRW per length per hour, NRW per customer per day, and NRW per service connection per day. In addition, it also aims to identify the determinates that influence NRW in Portugal.

The study utilized information sourced from ERSAR for 256 water companies in Portugal (excluding 17 with insufficient information, all based in Predominantly Rural Areas) for the years 2015-2020. In addition, information was extrapolated from a study by (Marques et al., 2005).

2.3.3.2. Variables

The IWA recommends NRW to be measured as a percentage from the water entering the system, although alternatively; NRW per connection and NRW per network length are also recommended (Alegre et al., 2006).Previous studies have identified a positive relationship between NRW and the length of the network (Alkasseh et al., 2013) , as a larger network would demand more finances to maintain and preserve its functionality (C. van den Berg, 2014).

According to(González-Gómez et al., 2012a), The relationship between NRW and connection density (expressed as the number of connections per km of length) is ambiguous, as the relationship can either be positive due to higher pressures required to provide sufficient water on all the elevations of a buildings; creating a higher risk of pipe leaks & bursts. While on the other hand a negative relationship can be expected as high-density areas require lower network coverage, thus lower maintenance cost per connection.

The study by (Lee et al., 2012), indicates a positive relationship between the pressure in the network and the frequency of leaks and bursts; urging water companies of the importance of maintaining the structural integrity of their pipe & overall water systems.

Table 2.15 exhibits the equations utilized to analyse the performance indicator for non-revenue water in the remaining 239 water supply companies in mainland Portugal.

Table 2.15 : Criteria and equations used for non-revenue water.

Code	Performance Indicator	Units	Formula
AA08	Non-revenue water	Percentage (%)	$AA08ab = \left(dAA53ab^{(i)}/dAA41ab^{(ii)}\right) * 100$
		Length of conduit per hour (l km^{-1} h^{-1})	$AA08ab = \left(\frac{dAA53ab * 1000}{dAA15b^{(iii)}}\right)/(365 * 24)$
		Customer per day (l cu^{-1} day^{-1})	$AA08ab = \left(\frac{dAA53ab * 1000}{dAA11b^{(iv)}}\right)/(365)$
		Service connections per day (l SC^{-1} day^{-1})	$AA08ab = \left(\frac{dAA53ab * 1000}{dAA18b^{(v)}}\right)/(365)$
		(i) Unbilled water (m3/ year) (ii) Water entering the system (m3/year) (iii) Total length of conduit (km) (iv) Accommodation with effective service (no.) (v) Connection extensions (no.)	

2.3.3.3. Results

The main characteristics of Portugal's water industry in the year 2019 are exemplified in Table 2.16. The findings indicate that the total water produced was approximately 825 hm^{3,} with the revenue water at 578 hm$^{3.}$ This implied that 30% of the total water entering the system was non-revenue water.

Table 2.16 : Main characteristics of the water industry in Portugal

Description	Units	Quantity
Inhabitants	no.	10 555 853 [(a)]
Coverage level	%	95.62
Distributed volume	hm^3	824.47
Revenue volume	hm^3	577.07
Domestic volume	hm^3	372.14
Water services	no.	256
Customers	no.	4715776
Mains	km	109432.5
Staff	no.	7717

[(a)]The value is from the 2011 census

The indicative results for NRW in percentage, the conduit length per hour, customer per day and by service connection per day for each of the 239 water companies is presented in Figures 2.2 - 2.4, including an analysis in Table 2.17.

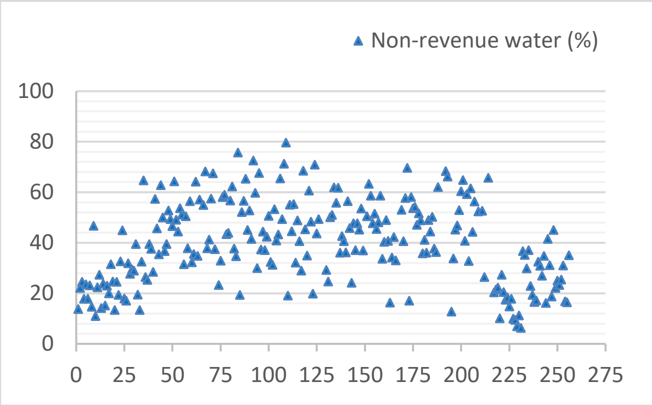


Figure 2.2: NRW (%)

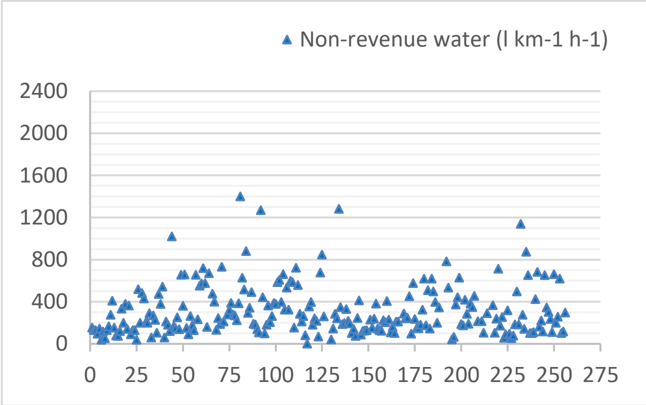


Figure 2.3: NRW (l .km $^{-1}$ h^{-1})

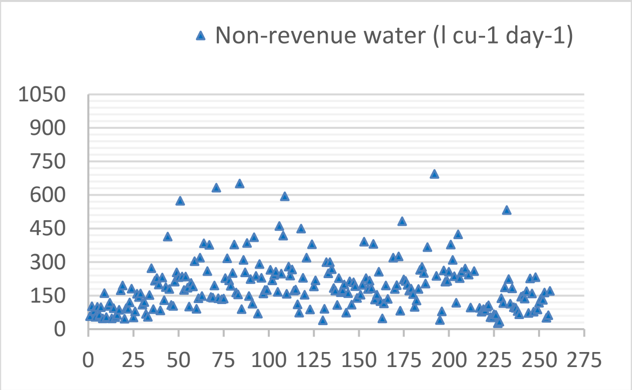


Figure 2.5 :NRW (l cu^{-1} day^{-1})

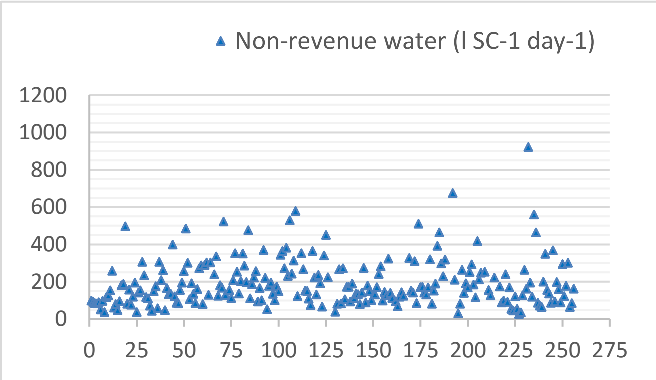


Figure 2.4 :NRW (l sc^{-1} day^{-1})

Table 2.17 : Assessment of Results

Fig.	Description
2.2	Having an average of 40% and a range from 6.3-79.9%; it appears there are water companies that are managing NRW exceptionally well and those that are struggling. Compared with results from 2005, the dominate range has moved from 30 – 40% to 40 – 50%.
2.3	195 out of 239 water companies experienced less than 400 l·km^{-1} h^{-1} of NRW. The results were similar to those from 2005 with slight improvement as only 5 water companies were above 1000 l·km-1 h^{-1}. In 2005 there were 28 water companies above this, with the highest being 3000 l·km^{-1} h^{-1} of NRW.
2.4	The results match those from 2005 in terms of obtaining an average in NRW of 200 l·cu^{-1} day^{-1} and a highest of 695 l·cu^{-1} day^{-1}; the only difference being that the 2005 results had 6 water companies with higher values.
2.5	220 out of 239 water companies experienced NRW of less than 400 l·sc^{-1} day^{-1}, with the highest value being 924 l·sc^{-1} day^{-1}. These results match those from 2005, although they had an addition of 6 water utilities above 924 l·sc^{-1} day^{-1}.

The relationship between the four types of NRW namely, NRW as a percentage, NRW per length per hour, NRW per customer per day, and NRW per service connection per day is examined in Table 2.18 and 2.19, respectively.

A range of four groups, composed of 60 water companies each, are created to accommodate the total 239 water company. Thereafter a ranking system was utilised to establish the positioning of 2 water companies (including Be Water - Águas de Ourém) after the application of all four NRW indicators and a differential margin was established.

Table 2.18 : Water Utility Ranking after application of NRW indicators - Águas de Ourém

Águas de Ourém					
Unit	Water Utility Ranking				Margin
	Group 1 (1-60)	Group 2 (60-120)	Group 3 (120-180)	Group 4 (180-240)	
(%)	-	-	-	189	14.6 %
($l\ km^{-1}\ h^{-1}$)	-	-	-	224	
($l\ cu^{-1}\ day^{-1}$)	-	-	-	191	
($l\ SC^{-1}\ day^{-1}$)	-	-	-	213	

Table 2.19 : Water Utility Ranking after application of NRW indicators - SMAS de Leiria

SMAS de Leiria					
Unit	Water Utility Ranking				Margin
	Group 1 (1-60)	Group 2 (60-120)	Group 3 (120-180)	Group 4 (180-240)	
(%)	-	-	147	-	9.6 %
($l\ km^{-1}\ h^{-1}$)	-	-	128	-	
($l\ cu^{-1}\ day^{-1}$)	-	-	124	-	
($l\ SC^{-1}\ day^{-1}$)	-	-	143	-	

Table 2.18 and 2.19 have attained results within the same boundaries, irrespective of the application of different units; with a differential margin of less than 15%. It is evident and the results reinforce the important of using different NRW indicators to assess the efficiency and effectiveness of the water distribution system and associated characteristics.

The correlation my not be very strong, although it displays a more realistic picture rather than the use of a single indicator (C. van den Berg, 2014). Some of the factors discovered to affect NRW by (González-Gómez et al., 2012a), include population density and growth, minimum percentage of the storage reservoir, model of distribution system (gravity fed or pumped), management and tariff structures as well as the financial obligations of the utility.

A study by (C. van den Berg, 2014) indicates that water utilities have limited or no control over the key drivers of water losses, However, they are partially linked to the physical characteristics of the water supply system (C. van den Berg, 2015b).

3. Case Study

3.1. Be Water - Águas de Ourém.

3.1.1. Introduction

Be Water – Águas de Ourém is a water company responsible for the management and operation of water systems in the municipality of Ourém since 1996 (Be Water Group Limited, 2013). Ourém is a small city geographically located in mainland Portugal; central west, under the Santarém district. The city’s historical value enables it to be part of the Leiria-Fátima Tourism Region; inclusive of several historic-tourist cities. Ourém covers an area of approximately 420 km^2 with 45 932 inhabitants and is divided into two distinct areas, the North known for its productive agriculture and the South for its high elevations which exceed 300 meters (Ferreira Reis, 2018).

Ourém municipality is subdivided into eighteen parishes and is bordered by the municipality of Pombal on the north, Ferreira do Zererê and Tomar on the east, Alvaiázere on the northeast, Torres Novas on the southeast, Alcacena on the southwest, and Leiria and Batalha on the west (Medrado Cardoso, 2019). Figure 3.1 exemplifies the geographical location of the Municipality of Ourém.

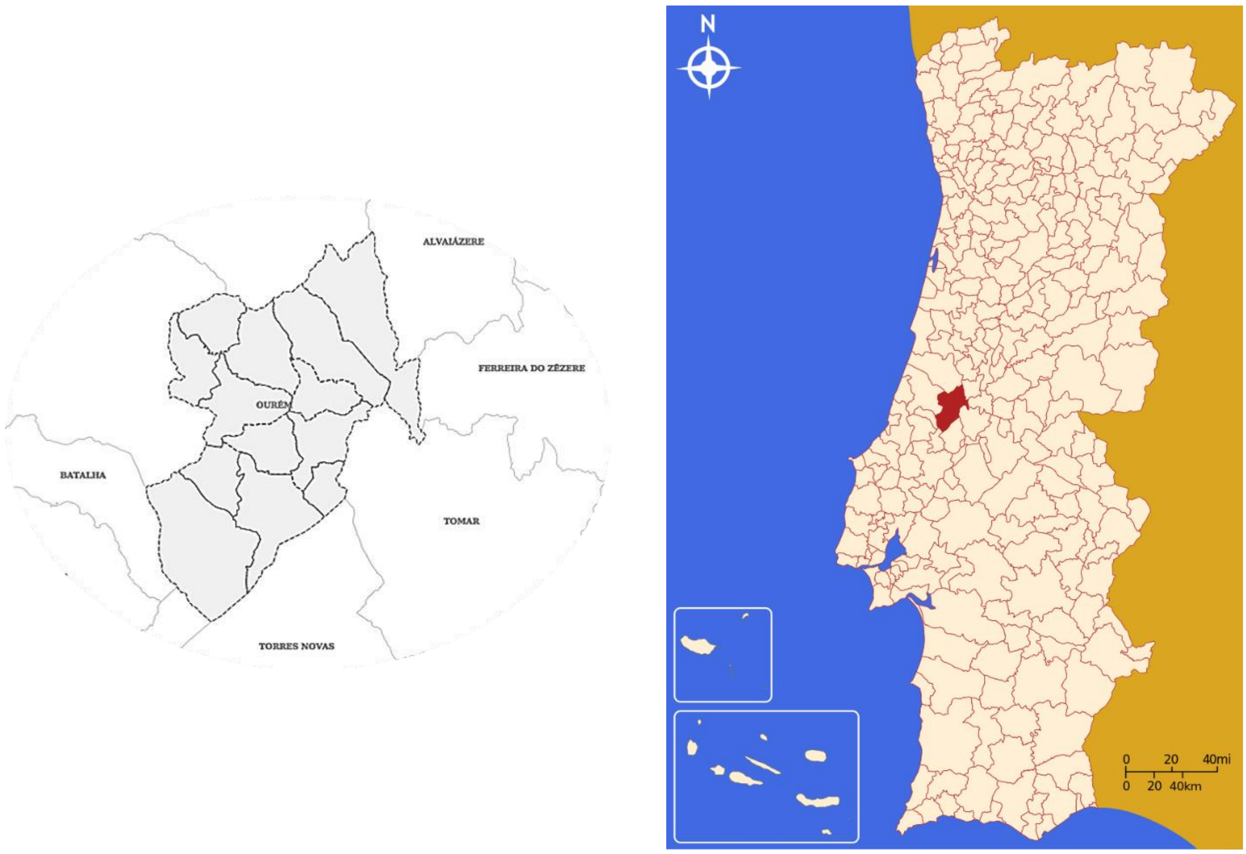


Figure 3.1: Geographical location of Ourém (Ferreira Reis, 2018; Rei, 2006)

In the process of exploration, collection, treatment, and distribution of water for public consumption, the organizational structure of Be Water - Águas de Ourém is displayed in Figure 3.2.

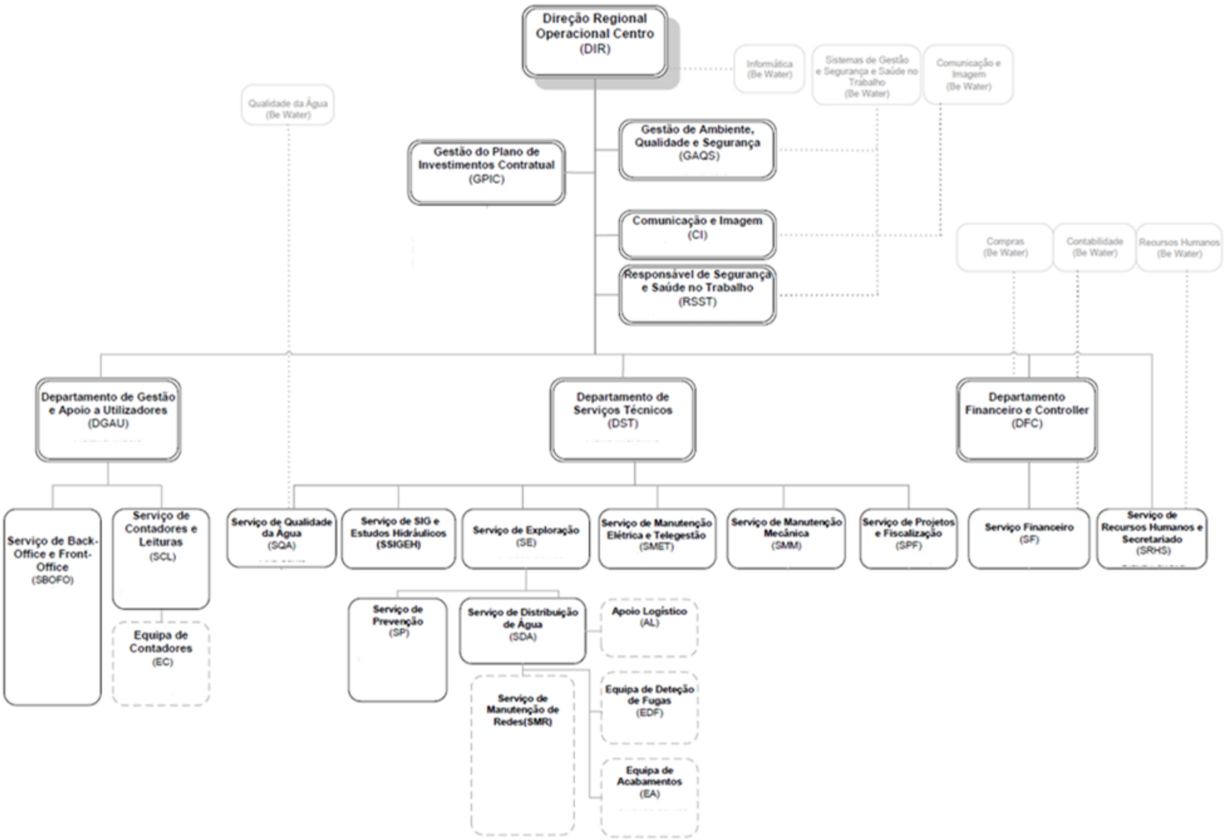


Figure 3.2 : Organisational Structure from Be Water – Águas de Ourém (Be Water - Águas de Ourém, 2019)

In 2019, the number of registered users was recorded as 26,506 with 2,512,617 m^3 of billed water, averaging a consumption rate of 7.98 m^3/ user/ month. In the same year 2,958 water quality examinations were carried out from the 19 catchments from which only 1 non-compliance with the maximum allowable value was obtained in the copper parameter.

A furthermore 2,735 examinations were carried out from reservoirs and fire hydrants to determine microbiological, physiochemical, and organoleptic parameter. Compliance was achieved with a rate of 99.88% (Be Water - Águas de Ourém, 2019).

Extensive sampling of water is amongst the many priorities and commitments made by Be Water - Águas de Ourém and this is evident in the company's performance when benchmarked.

3.1.2. Analysis of performance indicators and benchmarking

The methodology considered aims at attaining an empirical understanding of benchmarking amongst water companies in the same region, possessing similar characteristics such as serving moderately urban areas.

The procedure used was concerned with dividing mainland Portugal into 3 regions, and focusing on one category within one region, as per depiction in Table 3.1. The choice of region and cluster was influenced by the cooperation of one Water Company (Be Water - Águas de Ourém), whereby additional physical research and consultation on the 14 performance indicators, their influences and challenges would be possible.

This case study will thus focus on the moderately urban area of the centre region of Portugal, which accommodates 24 water companies. A benchmarking exercise will thereafter be conducted to determine their quality of service within the 14 regulated performance indicators.

Table 3.1 : Water Companies clusters

Region	Cluster	No. of Water Companies
North	PUA	10
	MUA	20
	PRA	50
Centre	PUA	11
	MUA	24
	PRA	67
South	MUA	16
	PRA	58

PUA - Predominantly Urban Area; MUA - Moderate Urban Area; PRA- Predominantly Rural Area

As a pivotal part of this study, the performance of Be Water - Águas de Ourém, will be assessed among the other water companies within this cluster, and compared with the national and cluster average performance.

The results from the analysis will provide guidance with regards to which indicator should be prioritised due to poor quality of service or leak of improvement, failure to provide information and other limitations. Furthermore, the study aims to reveal other features and consistency's/or inconsistencies on a national scale, compared to a cluster level.

3.1.3.1 Physical accessibility of the service (AA 01)

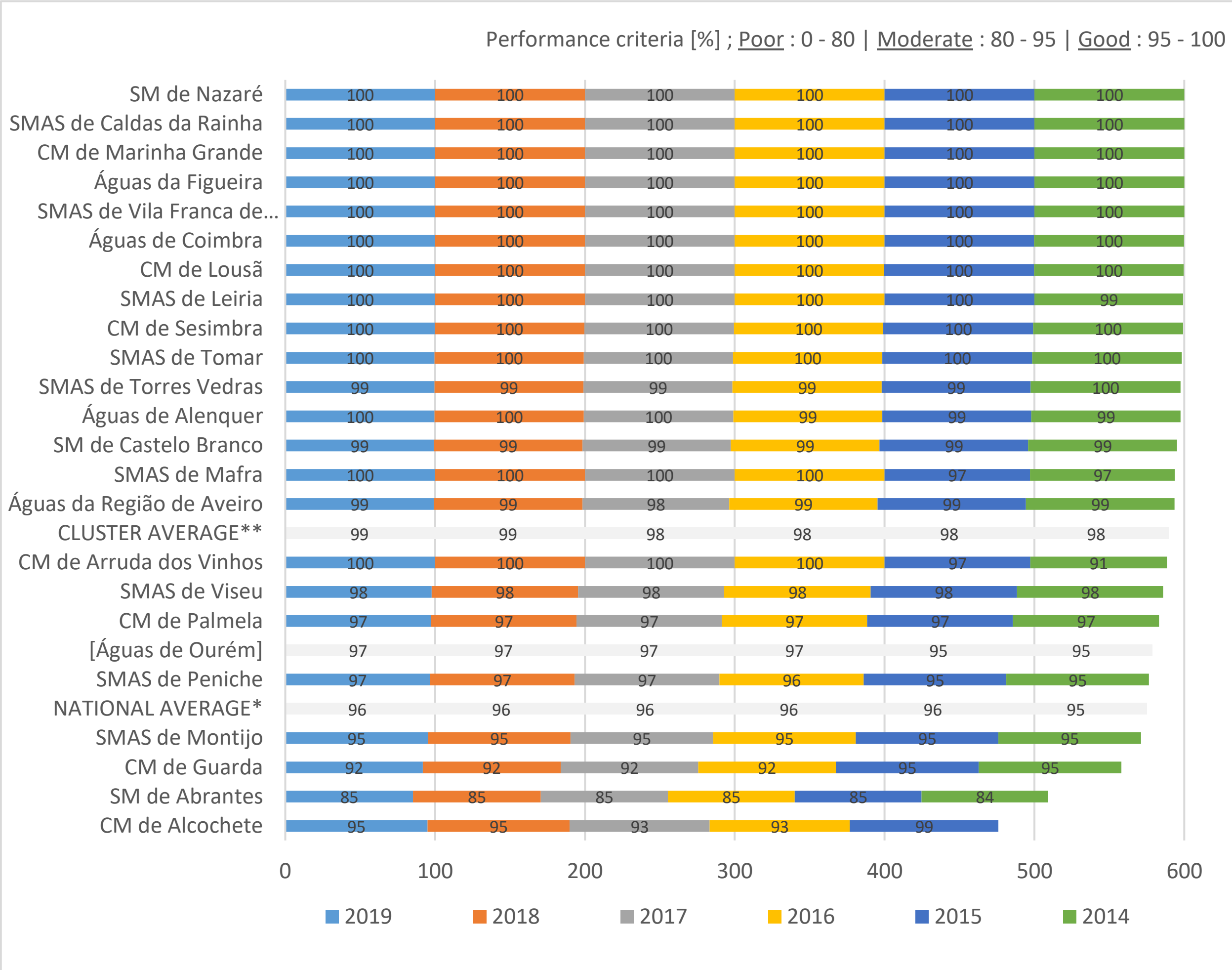


Figure 3.3 : Physical accessibility of the service – AA01

This indicator aims to determine the adequacy of the physical infrastructure from the water company to the end users; and can be expressed as a percentage of the total number of households in the area served by the water company. The results are obtained by the application of formula (3.2).

$$AA01b = (dAA11b + dAA12b)/dAA13b \times 100 \tag{3.2}$$

Where $dAA11b$ are the households with effective services (no.); $dAA12b$ are households with non-effective available services (no.); and $dAA13b$ are the total existing households (no.).

Figure 3.3 exemplifies a good quality of service from the national average throughout the period of the analysis, although the cluster average performed better; with more than 60% of the water companies attaining a service score between 99-100% in physical accessibility to the service.

Be Water – Águas de Ourém achieved results well between the national and cluster average, starting at 95% in 2014, thereafter maintaining a 2% increase from 2016 to 2019.

3.1.3.2 Economic accessibility of the service (AA 02)

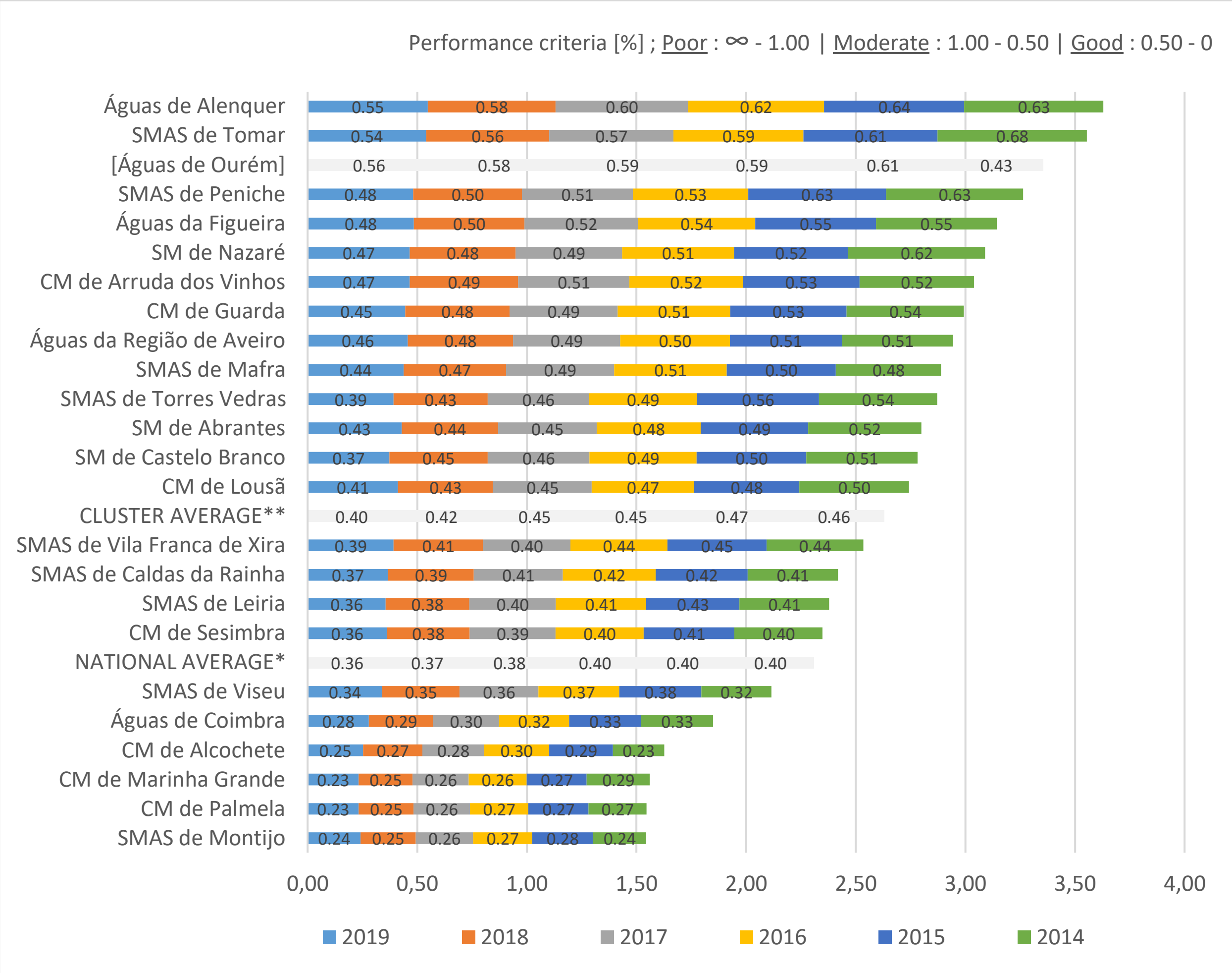


Figure 3.4: Economic accessibility of the service – AA02

The aim of this indicator is to assess the affordability of the services provided by the water company in relation to the economic capacity (disposable income) per household in the water company's intervention area. The results are obtained by the application of formula (3.3).

$$AA02ab = dAA84ab/dAA85ab \times 100 \qquad (3.3)$$

Where $dAA84ab$ is the average cost for the water supply services (€/year); and $dAA85ab$ is the household disposable income (€/ year).

Figure 3.4 exemplifies a good quality of service which is maintained over the evaluation period from the national average; by steadily decreasing from 0.40% to 0.36%. The cluster average displayed similar performance by steadily decreasing from 0.46% to 0.40%.

The results for Be Water – Águas de Ourém sharply increased between 2014 and 2015 from 0.48% to 0.61% and thereafter gradually decreased. The performance criteria achieved by Be Water – Águas de Ourém is a moderate quality of service, which is still considered acceptable.

3.1.3.3 Occurrence of water supply failures (AA 03)

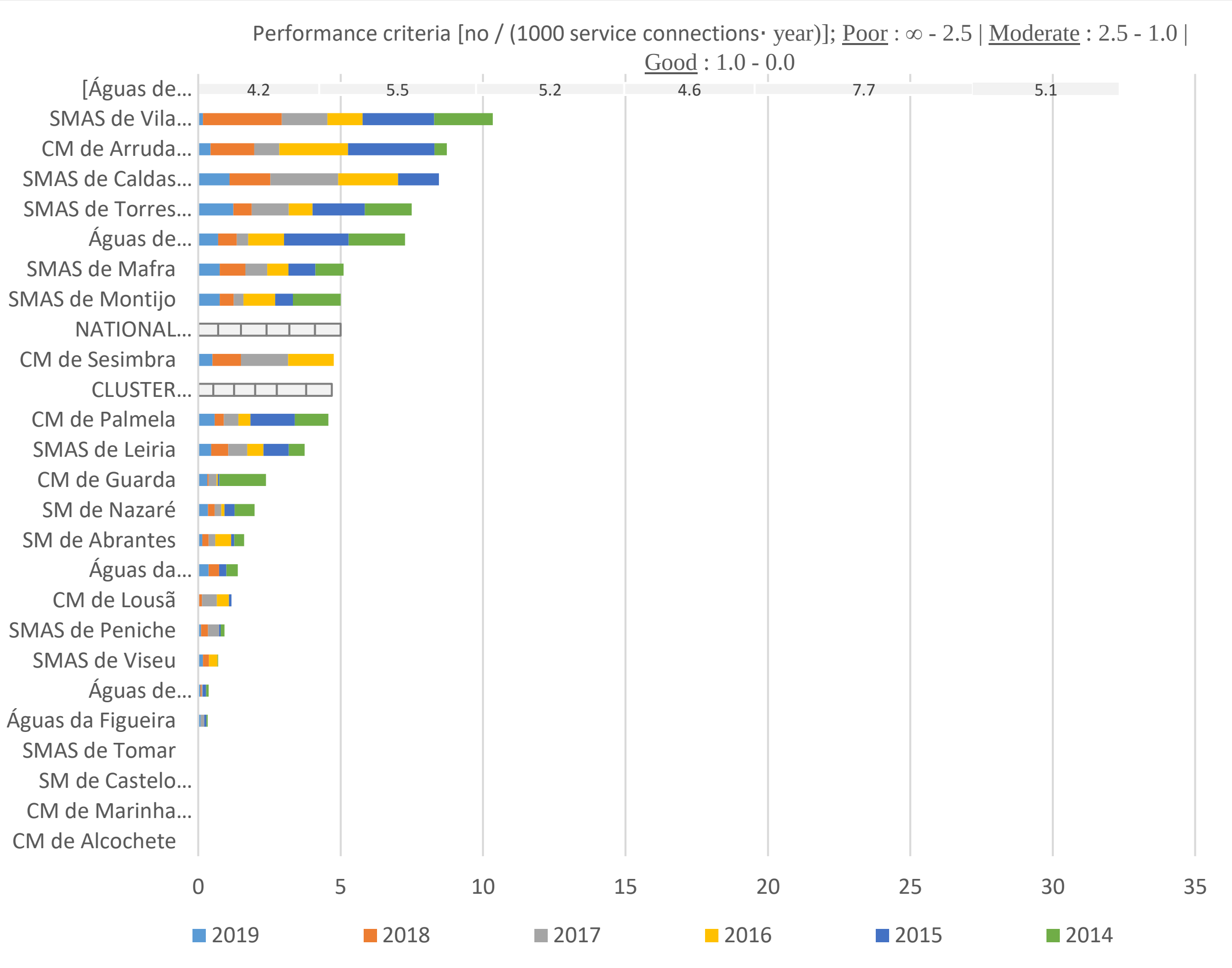


Figure 3.5 : Occurrence of supply failures – AA03

This indicator aims to assess the frequency of interruptions that occur in the service provided to the users by the water company. It is defined as the number of supply failures per 1000 service connections per year. The results are obtained by the application of formula (3.4).

$$AA03b = dAA35b / dAA18b \times 1000 \qquad (3.4)$$

Where $dAA18b$ are the service connections (no.); and $dAA35b$ are the supply failures (no. /year).

Figure 3.5 displays results of the national average achieving good quality of service, starting at 0.9 in 2014 and decreasing to 0.7 in 2019. The cluster average performed slightly better with results also starting at 0.9 in 2014, although ending at 0.5 in 2019.

Be Water – Águas de Ourém was the worst performing water company in the cluster, with poor quality of service results. Although since 2017 there has been a regression from 7.7 to 4.2 equivalent occurrence of water supply failures. It is recommended that Be Water - Águas de Ourém continue to explore possible solutions to improve this indicator, as it surpasses the other utilities by a large margin.

3.1.3.4 Safe water (AA 04)

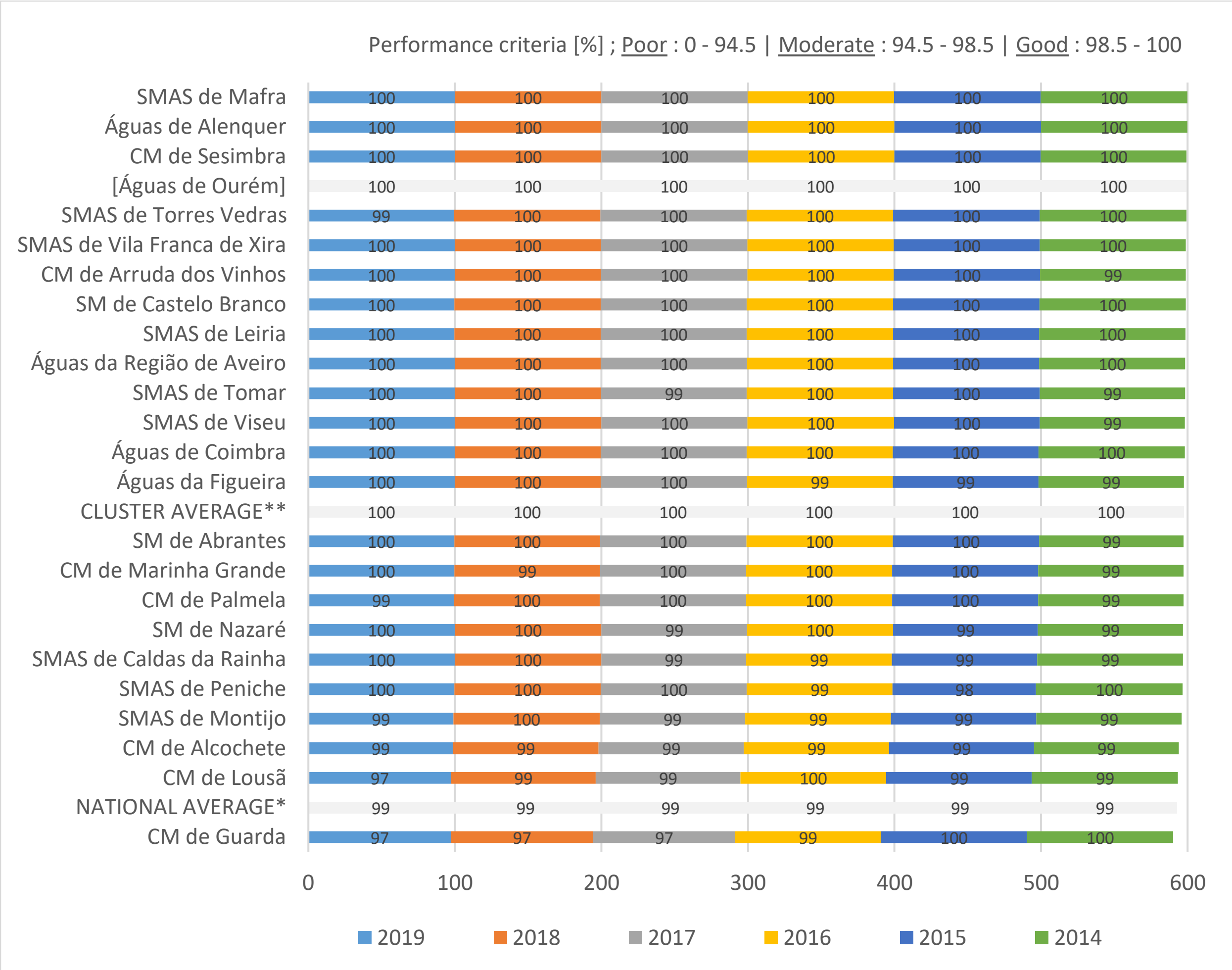


Figure 3.6: Safe water – AA04

This indicator intends to assess the quality of water supplied by the water company. It is defined as the percentage of good quality water in terms of compliance with the frequency of sampling, parameters set in the legislation and inspection control as defined in the Water Quality Control Plans. The results are obtained by the application of formula (3.5).

$$AA01b = (dAA40ab/dAA38ab) \times (dAA37ab/dAA39ab) \times 100 \qquad (3.5)$$

Where $dAA37ab$ is mandatory water quality analyses (no./year); $dAA38ab$ is the analyses carried out on parameters with parametric values (no./year); $dAA39ab$ is mandatory regulatory water quality analyses (no./year); and $dAA40ab$ is the analyses performed in compliance with the parametric value (no./year).

Figure 3.6 exemplifies the national average performing exceptionally well over the last 6-year evaluation period, achieving a constant 99% result. The cluster average accomplished better results, with a constant 100%. Be Water – Águas de Ourém was amongst the best performing water companies in the cluster, with exceptional results.

3.1.3.5 Response to complaints and suggestions (AA 05)

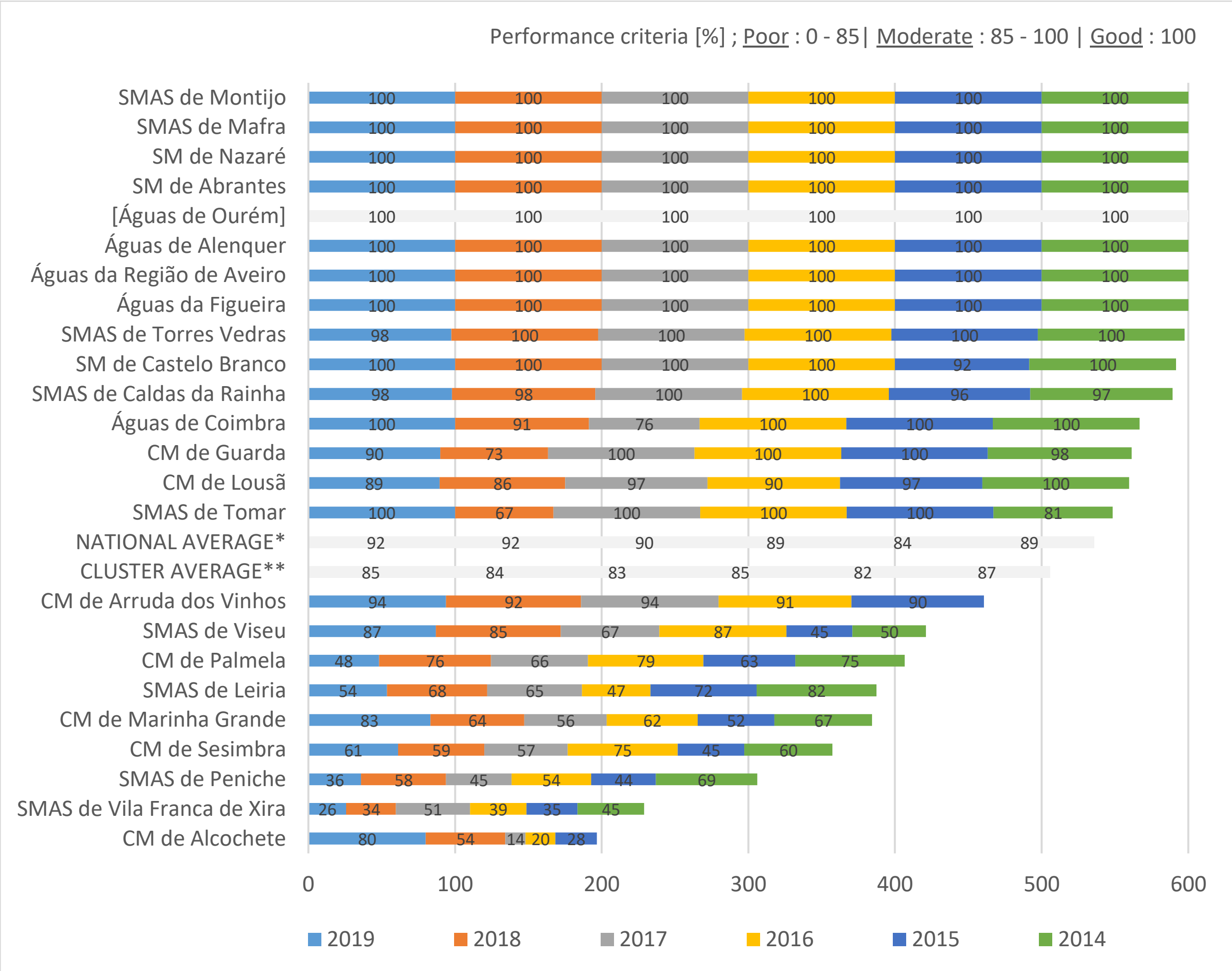


Figure 3.7 : Responding to complaints and suggestions – AA05.

The aim of this indicator is to evaluate the quality of service provided to the user in relation to the water company´s response to complaints and written suggestions from the user. The results are obtained by the application of formula (3.6).

$$AA05ab = dAA70ab / dAA69ab \times 100 \qquad (3.6)$$

Where $dAA69ab$ are the complaints and suggestions (no./year); and $dAA70ab$ are the replies to complaints and suggestions (no./year).

Figure 3.7 exemplifies the national average achieving moderate results, gradually improving from 89% in 2014 to 92% in 2019. The cluster average also achieved moderate results, which fluctuated between 87% - 83%.

The cluster average was influenced by an equal divide; with 50% of the water companies accomplishing good-moderate results, while the others performed poorly. Be Water – Águas de Ourém performed outstandingly well, achieving 100% throughout the evaluation period, amongst 7 other water companies with the same results.

3.1.3.6 Spending coverage (AA 06)

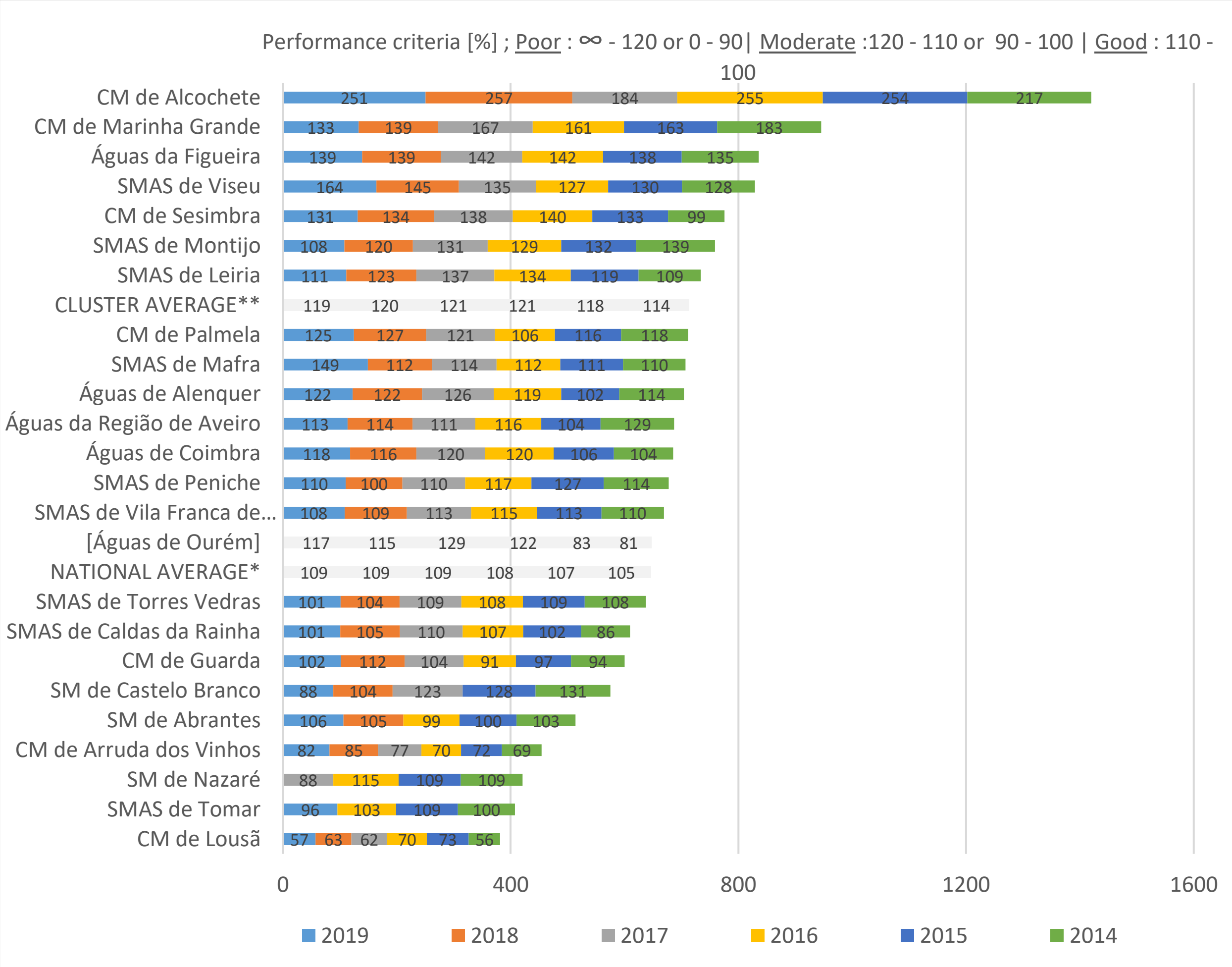


Figure 3.8: Spending coverage – AA06

This indicator aims to measure the water company's economic and financial levels of sustainability in relation to its ability to generate income from its activities. This is defined by the ratio of total income (tariff's, other income, and subsidies) and total expenditure. The results are obtained by the application of formula (3.7).

$$AA06ab = (dAA80ab + dAA81ab + dAA82ab)/dAA83ab \times 100 \qquad (3.7)$$

Where $dAA80ab$ is the tariff income (€/year); $dAA81ab$ is other income (€/year); $dAA82ab$ is investment subsidies (€/year); and $dAA83ab$ are total expenses (€/year).

Figure 3.8 exemplifies the national average performing exceptionally well, maintaining a good quality of service throughout the evaluation period.

The performance of the cluster average indicated a moderate quality of service, this was due to the variation in performance from the individual companies whereby 45% of the water companies performed poorly, 37% performed moderately and only 18% resulted in a good quality of service. Be Water – Águas de Ourém displayed poor quality of service from 2014 to 2017 and improved to a moderate quality of service in 2018 and 2019.

3.1.3.7 Service subscription (AA 07)

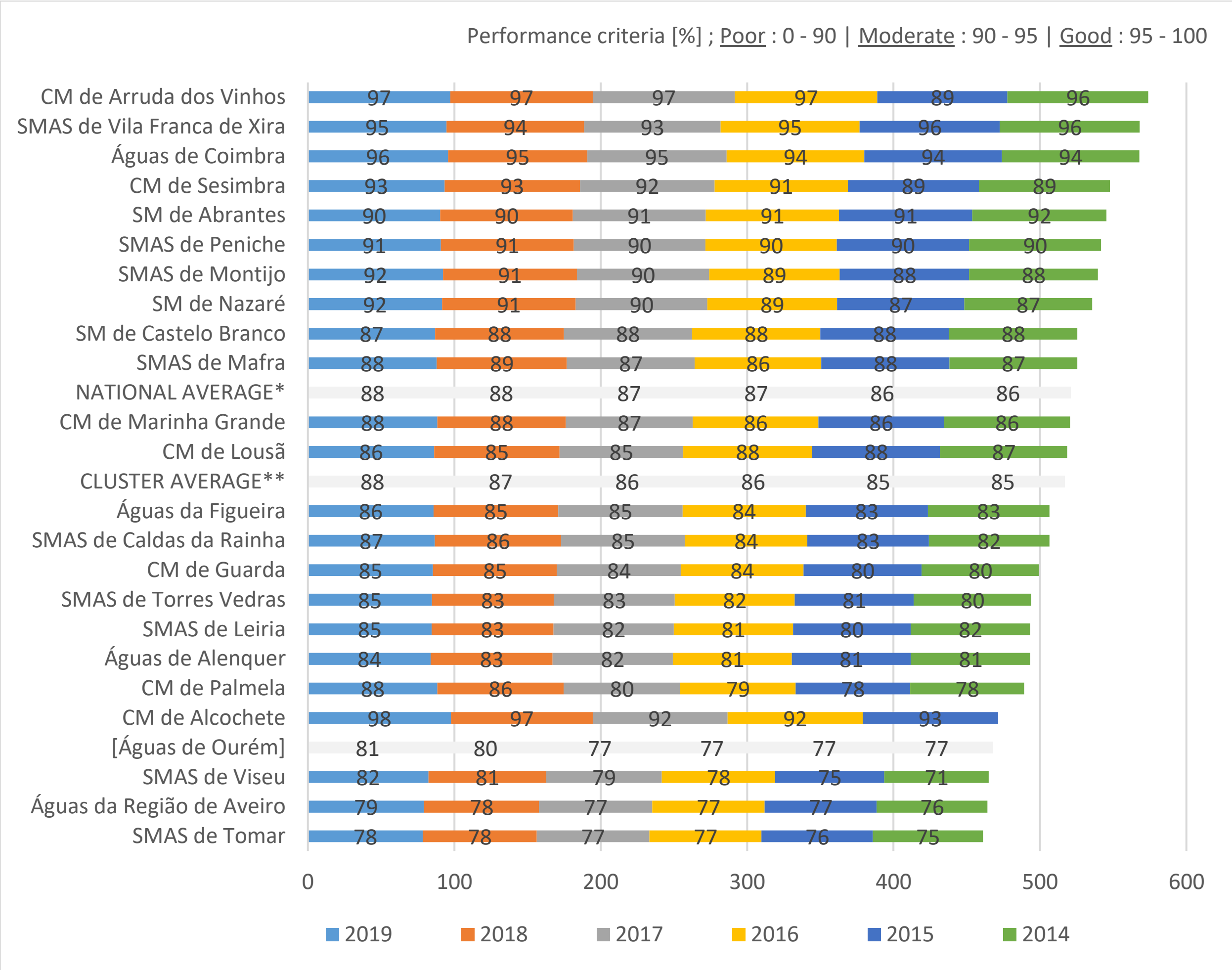


Figure 3.9: Service subscription – AA07

This indicator intends to assess the economic and financial stability of the water companies in relation to the connection of users to the physical infrastructure. This is defined as a percentage of the total number of households in the vicinity of the water company that have available and effective services in the water distribution infrastructure. The results are obtained by the application of formula (3.8).

$$AA07b = dAA11b/(dAA11b + dAA12b) \times 100 \qquad (3.8)$$

Where $dAA11b$ are the households with effective services (no.); and $dAA12b$ are households with non-effective available services (no.).

Figure 3.9 exemplifies the national average experiencing a 2% increase gradually over the last 6-year evaluation period, although it remains in the ‘poor quality of service’ category. The cluster average exhibited similar behaviour, with an overall 3% gradual increase from 85% to 88%: with the cluster performance distribution being 66.6% poor quality, 20.8% moderate quality, and 12.5% good quality performance.

Be Water – Águas de Ourém was amongst the worst performing companies in the cluster, with a constant of 77% from 2014 - 2017 and an increase to 81% in 2019.

3.1.3.8 Non-revenue water (AA 08)

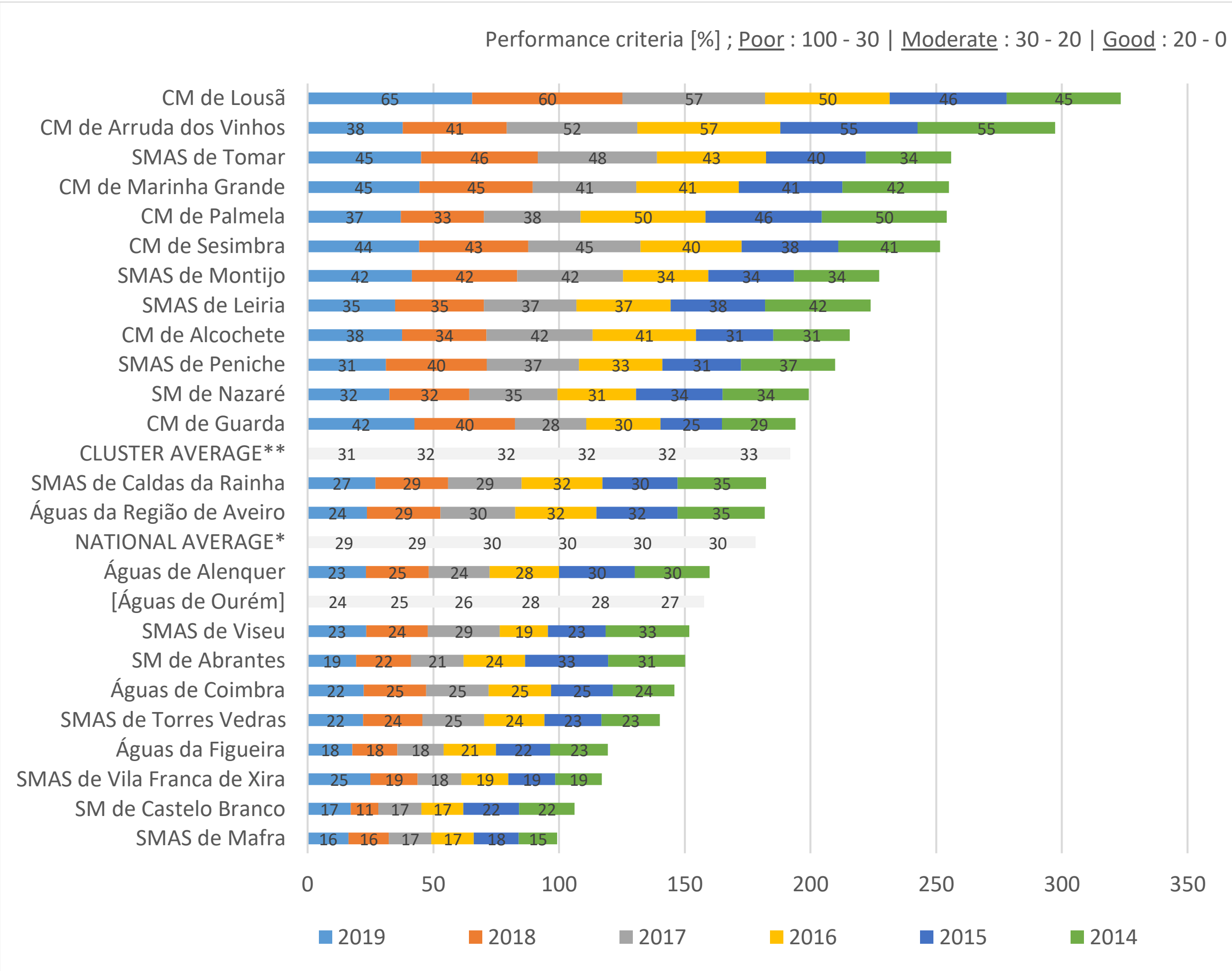


Figure 3.10 : Non-revenue water – AA08

The aim of this indicator is to assess financial management sustainability in reference to water losses, which despite being collected, treated, transported, stored, and distributed is not billed to the user. It is described as the water entering the system, and not billed. The results are obtained by the application of formula (3.9).

$$AA08ab = dAA53ab/dAA41ab \times 100 \quad (3.9)$$

Where $dAA41ab$ is water entering the system (m3/year); and $dAA53ab$ is non-revenue water (m3/year).

Figure 3.10 exemplifies the national average with a moderate quality of service, maintaining a constant 30% from 2014 to 2017, and thereafter experiencing a 1% decrease in 2018.

The cluster average achieved poor quality results; with a slight decrease from 33% to 31% over the evaluation period. The results from the cluster were influenced by 50% of the water companies performing poorly, while the other 50% performed moderately and good, with constantly decreasing non-revenue water. Be Water – Águas de Ourém has achieved a moderate quality of service, with results decreasing from 27% to 24% during the evaluation period.

3.1.3.9 Network rehabilitation (AA 09)

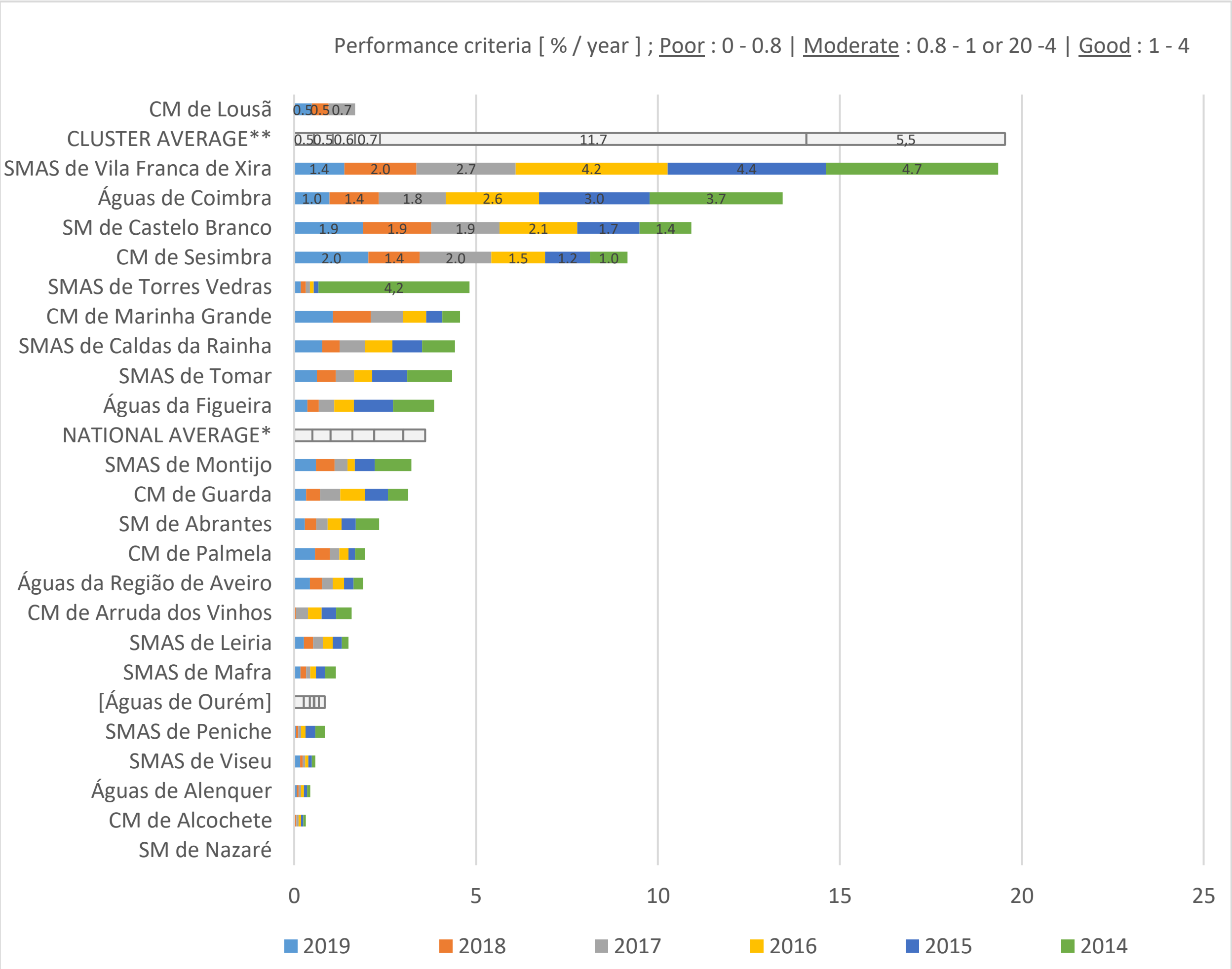


Figure 3.11 : Network rehabilitation – AA09

This indicator aims to assess sustainability regarding the management of infrastructure; particularly the continues practice of network rehabilitation. The indicator is defined as the average annual percentage of distribution network with more than 10-years in age, that has been rehabilitated in the last 5-years. The results are obtained by the application of formula (3.10).

$$AA09ab = dAA17ab/dAA16ab \times 100/5 \tag{3.10}$$

Where $dAA16ab$ is the average length of pipeline (km); and $dAA17ab$ is the rehabilitated pipelines over the last 5 years (km).

Figure 3.11 exemplifies the national average with poor results, which varied during the evaluation period between 0.5% to 0.8% per year. The performance of the cluster average declined from moderate quality of service in 2014 and 2015 to poor quality of service from 2016 to 2019. Only 16% of the water companies achieved good quality performance, approximately 70% performed poorly and 14% experienced a moderate quality of service. Be Water – Águas de Ourém was amongst the utilities which performed poorly, during the evaluation period.

The water company indicated that network renovation goals are established mainly through a contract between themselves and the municipality, and after the end of the concession there is no motivational factor or return on investment in efforts to improve this indicator.

3.1.3.10 Occurrence of faults in pipes (AA 10)

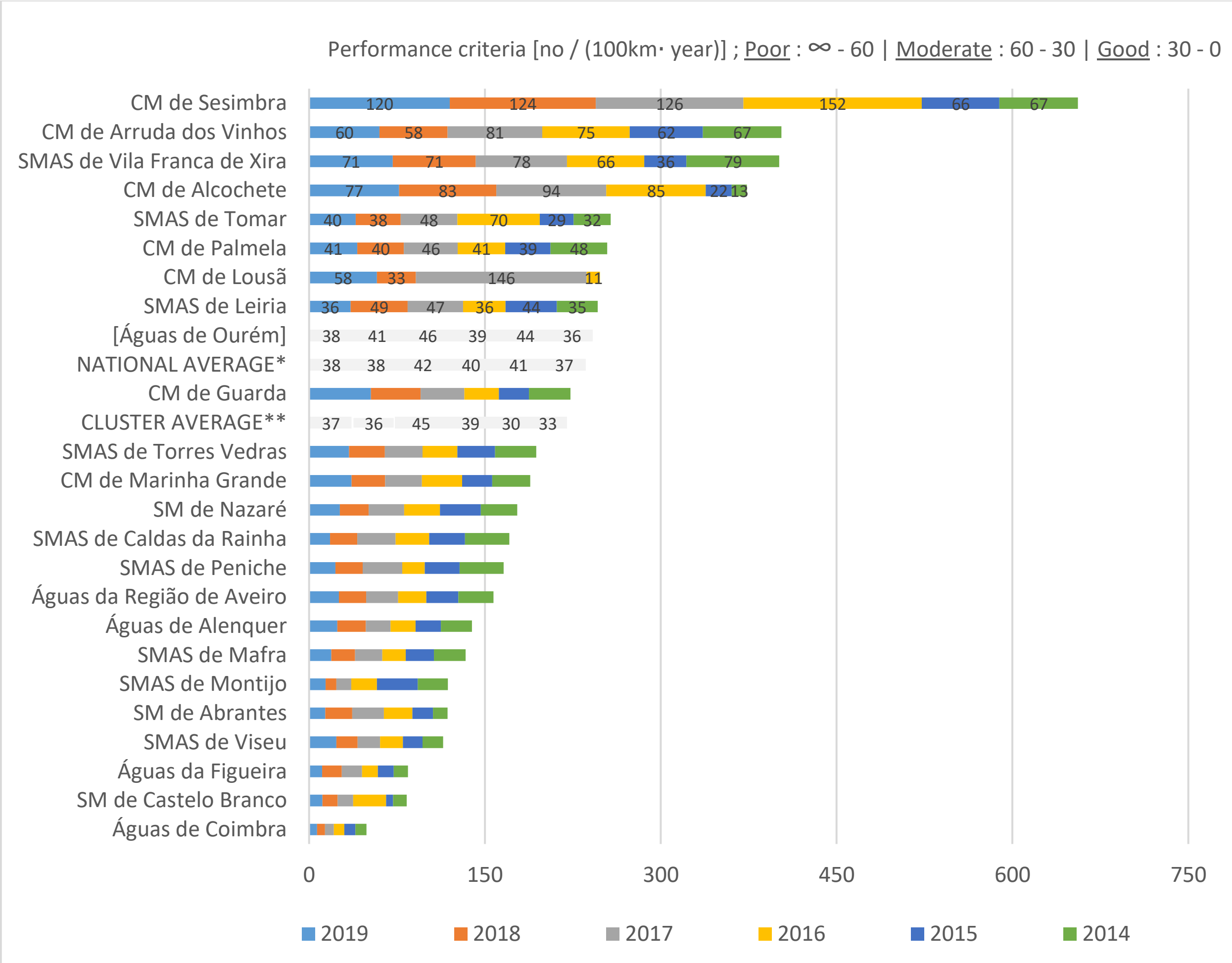


Figure 3.12 : Occurrence of faults in pipes – AA10

This indicator intends to assess the water companies' infrastructure sustainability regarding the reduced frequency of damage to the pipes. It is defined as the annual number of faults in pipes per 100 km of the network. The results are obtained by the application of formula (3.11).

$$AA10ab = dAA36ab/dAA15ab \times 100 \qquad (3.11)$$

Where $dAA15ab$ is the total length of pipeline (km); and $dAA36ab$ are the faults in the pipeline (no./year).

Figure 3.12 exemplifies the national average with a moderate quality of service with results starting at 37 faults in 2014 and rising to 42 faults in 2017, and thereafter decreasing to 38 faults in both 2018 and 2019. The cluster average had similar performance to the national, with the most unfavourable results also in 2017 at 45 faults.

Over the evaluation period, 45% of water companies within the cluster resulted in good quality of service, 37% with a moderate quality, and 18% with poor quality of service.

Be Water – Águas de Ourém obtained moderate quality of service, with results varying between 46 to 36 faults, and experiencing the most unfavourable results in 2017.

3.1.3.11 Adequacy of human resources (AA 11)

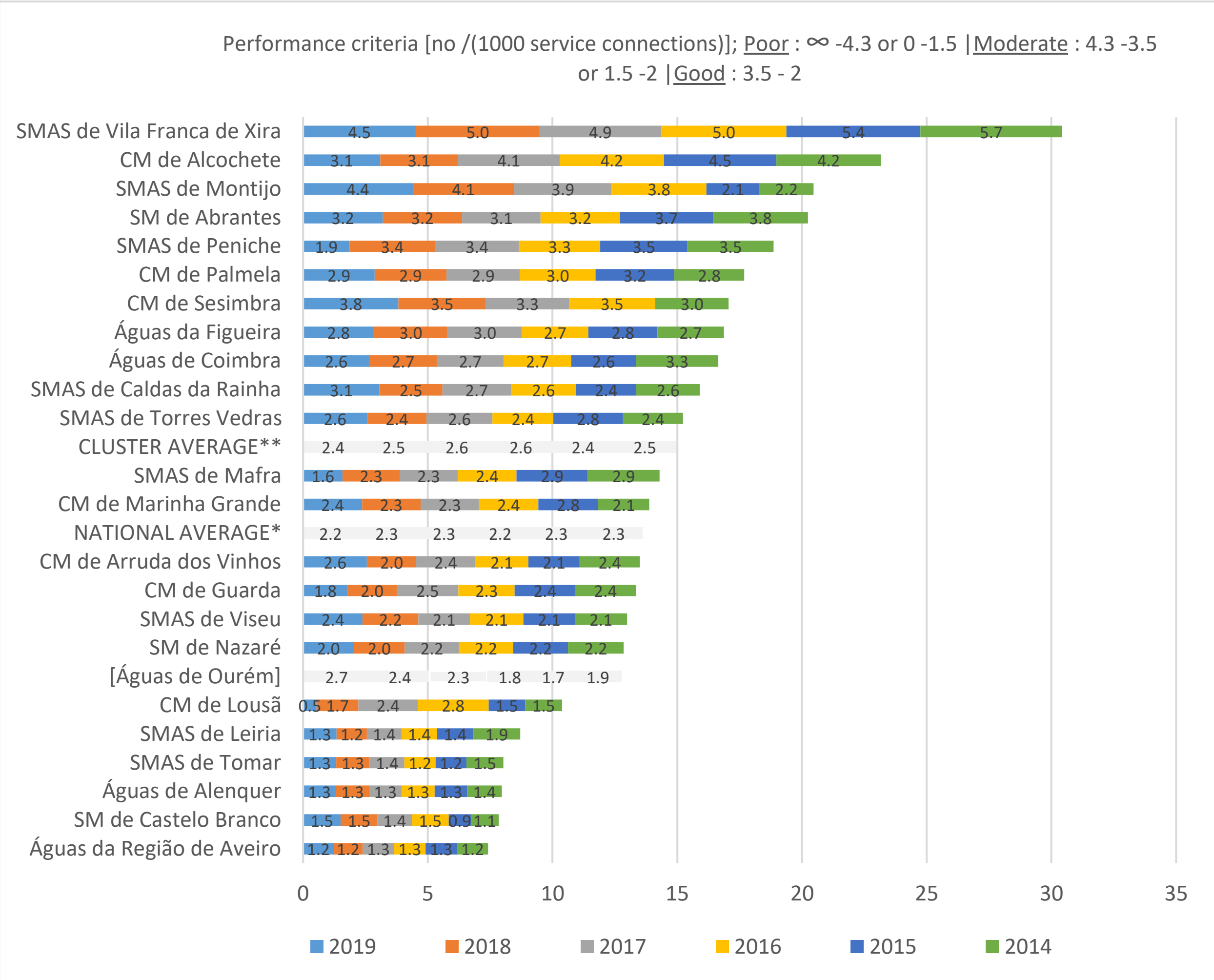


Figure 3.13 : Adequacy of human resources – AA11

The aim of this indicator is to assess management sustainability in terms of human resources productivity. It is defined as the equivalent annual number of full-time employees assigned to the water supply service per 1000 service connections. The results are obtained by the application of formula (3.12).

$$AA11b = (dAA09b + dAA10b)/dAA18b \times 1000 \qquad (3.12)$$

Where $dAA09b$ is the Personnel involved in the water supply service (no.); $dAA10b$ are the outsourced personnel working in the water supply service (no.); and $dAA18b$ are the connection extensions (no.).

Figure 3.13 exemplifies the national average with a good quality of service having results varying between 2.3 and 2.2 equivalent people throughout the evaluation period. The cluster average also obtained good quality, with varying results between 2.4 and 2.6 equivalent people. The performance of Be Water – Águas de Ourém was progressive from a moderate quality of service in 2014 – 2016 to a good quality of service from 2017 – 2019.

3.1.3.12 Water losses (AA 12)

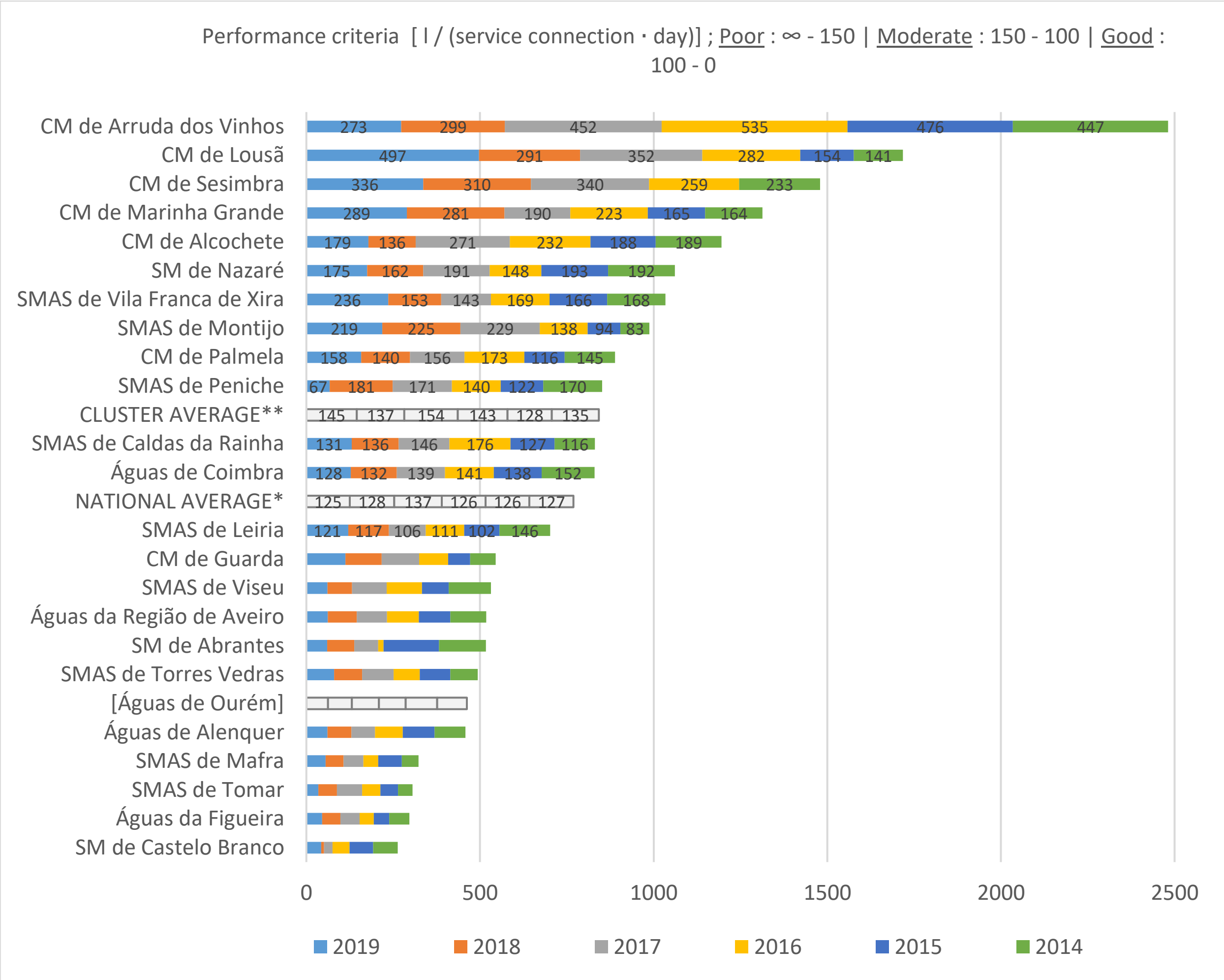


Figure 3.14 : Water losses – AA12

This indicator intends to assess the efficiency in the use of environmental resources regarding water losses. It is defined as the daily volume of real losses per service connection. The results are obtained by the application of formula (3.13).

$$AA12b = (dAA55b/dAA18b) \times (1000/365) \qquad (3.13)$$

Where $dAA18b$ are the service connections (no.); and $dAA55b$ are the actual water losses (m3/year).

Figure 3.14 exemplifies a moderate quality of service from the national average, with varying results from 125 to 137 litters per service connection per day. The cluster average also experienced a moderate quality of service throughout the evaluation period, excluding the year 2017 whereby the performance was recorded as 157 litters per service connection per day (poor quality).

Majority of the water companies experienced their most unfavourable performance in the year 2017, although this was not the case with Be Water – Águas de Ourém. It achieved a good quality of service with results varying between 62 and 91 litters per service connection per day, which reflects a good quality of service.

3.1.3.13 Energy efficiency of pumping installations (AA 13)

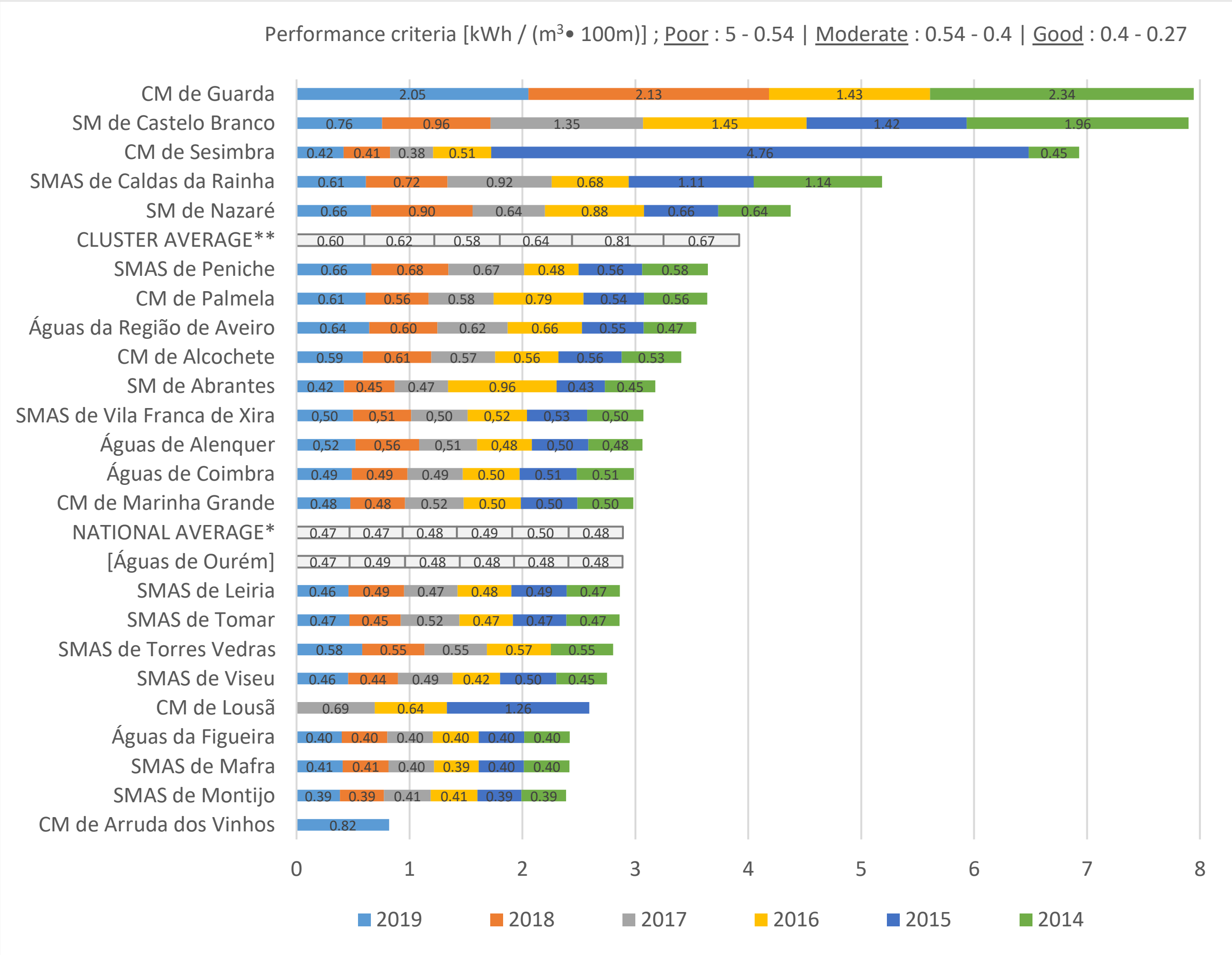


Figure 3.15 : Energy efficiency of pumping installations – AA13

The aim of this indicator is to assess environmental sustainability in the appropriate use of energy resources. It is defined as the normalized average energy consumption of pumping installations. The results are obtained by the application of formula (3.14).

$$AA13ab = dAA61ab/dAA62ab \quad (3.14)$$

Where $dAA61ab$ is the energy consumption for pumping (kWh/year); and $dAA62ab$ is the smoothing factor (m3/year • 100m).

The results for the quality of service are based on the energy efficiency criteria in Table 3.2.

Table 3.2 : Energy Efficiency criteria

Quality of service description	Avg. Energy Efficiency [%]	Performance Indicator [kWh / (m³ ·100 m)]
Good	100 – 68 %	0.27 – 0.40
Moderate	68 – 50 %	0.40 – 0.54
Poor	Below 50 %	0.54 – 5.00

Figure 3.15 exemplifies the national average with a moderate quality of service, however the cluster average displayed results of poor quality of service ranging between 0.6 – 0.81 equivalent energy efficiency, over the evaluation period. Even though close to 60% of the water companies have displayed poor quality of service, Be Water – Águas de Ourém has achieved a moderate quality of service.

3.1.3.14 Proper handling of treatment sludge (AA 14)

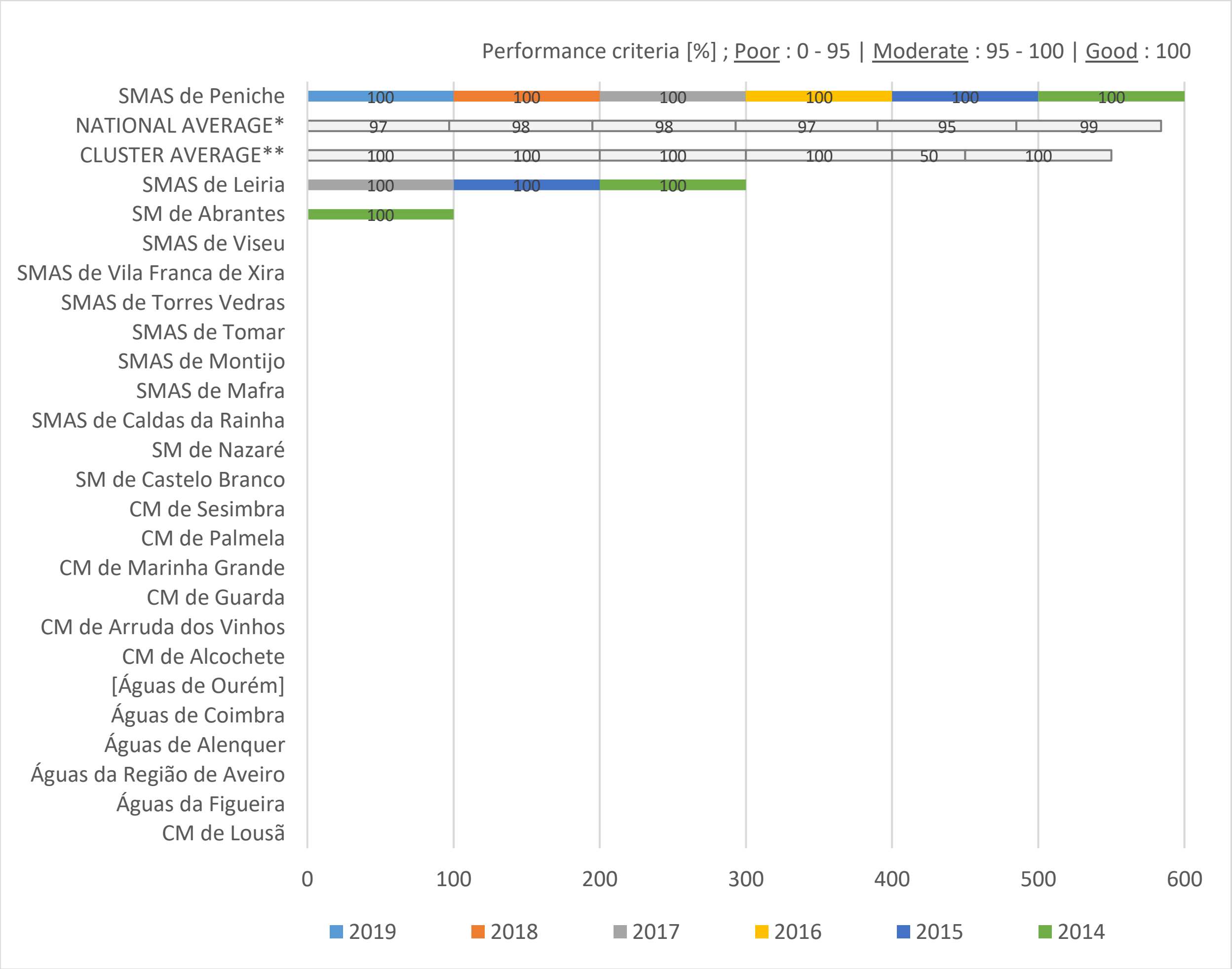


Figure 3.16 : Proper handling of treatment sludge – AA14

This indicator aims to assess environmental sustainability regarding efficiency in preventing pollution during the handling of sludge produced during water treatment as it is a potential contaminate to natural resources.

It is defined as the percentage of sludge from the water treatment, delivered to a licenced operator. The results are obtained by the application of formula (3.15).

$$AA14ab = \frac{[(dAA65ab \times 0.18)+(dAA67ab \times 0.60)]}{[(dAA66ab \times 0.18\,)+\,(dAA68ab \times 0.60)]} \times 100 \qquad (3.15)$$

Where $dAA65ab$ is the dehydrated sludge delivered to licensed operator (t/year); $dAA66ab$ is the dehydrated sludge drained from treatment facilities (t/year); $dAA67ab$ is the dry sludge delivered to licensed operators (t/year); and $dAA68ab$ is the dry sludge drained from treatment facilities (t/year).

Figure 3.16 exemplifies the national average with a moderate quality of service, over the evaluation period with results varying between 99 - 95%. However, the cluster average is indeterminable, due to a limited set of data. Only 3 out of the 24 water companies within this cluster produced results; this may be due to water companies either not providing information to the regulator or not having a sludge producing water treatment station.

Be Water - Águas de Ourém does not have a sludge producing treatment station.

3.1.3.15 Summary of the performance indicators from Be Water – Águas de Ourém.

The overview of the performance indicators from Be Water - Águas de Ourém is presented in Figure 3.17; whereby the aim is to (1) benchmark Be Water - Águas de Ourém in reference to the performance of the whole cluster, and (2) asses the cluster performance in individual PIs.

To qualify for consideration in this evaluation, individual water companies must have produced performance results throughout the 6-year evaluation period, within each performance indicator.

Figure 3.17 : Performance and Benchmarking for Be Water – Águas de Ourém

The performance indicators from Be Water – Águas de Ourém predominantly produced good or moderate quality of service, with only 3 performance indicators resulting in poor quality of service.

Be Water – Águas de Ourém's best performance was recorded under Safe water (AA 04), Response to complaints and suggestions (AA 05) as well as water losses (AA 12). These were followed by adequacy of human resources (AA 11), spending coverage (AA 06), and physical accessibility of the service (AA 01).

The worst performing indicators were Occurrence of water supply failures (AA 03); which had results that were approximately 3 times unsuitable compared to other water companies. It was followed by Service subscription (AA 07) and Network rehabilitation (AA 09). Be Water – Águas de Ourém indicated that PI´s such as network rehabilitation depend on contract between themselves and the municipality, and after the end of the concession there is no motivational factor or return on investment in efforts to improve this indicator.

However, it is essential to assess the interdependency of some of the performance indicators to understand the dynamics and influences they have on each other, and moreover on the functioning and operation of the water company. Figure 3.18 illustrates the relations and performance of the identified indicators from Be Water – Águas de Ourém.

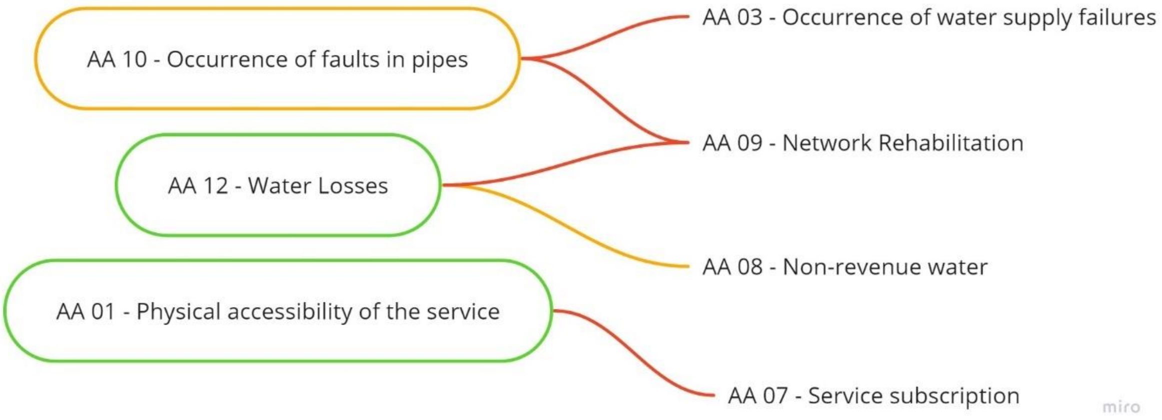


Figure 3.18 : Interdependent performance indicators from Be Water – Águas de Ourém

The occurrence of faults in pipes (AA 10), directly affects the occurrence of water supply failures (AA 03) and the Network rehabilitation (AA 09). These indicators are all related to the integrity and sustainability of the infrastructure.

Theoretically, it can be presumed that the efforts applied in the rehabilitation of the network will result in the reduced occurrence of faults in the pipes as well as the occurrence of water supply failures. Furthermore, Figure 3.18 illustrates that the decision to rehabilitate the network would not be influenced by water losses (AA 12), as this performance indicator achieved a good quality of service.

Concerning Non-revenue water (AA 08), it can also be assumed that this indictor is more likely to be influenced by Apparent losses and unbilled authorised consumption rather that Water losses (AA 12).

The poor quality of service from the performance indicator service subscription (AA 07) is less likely to be influence by the physical accessibility of the service (AA 01), as it achieved a good quality of service. The results may be influenced by the nature of the environment (moderately urban area), whereby some of the residence may be utilizing independent ground water extraction systems.

3.1.3. Procedure used by Be Water – Águas de Ourém to obtain the performance indicators

.

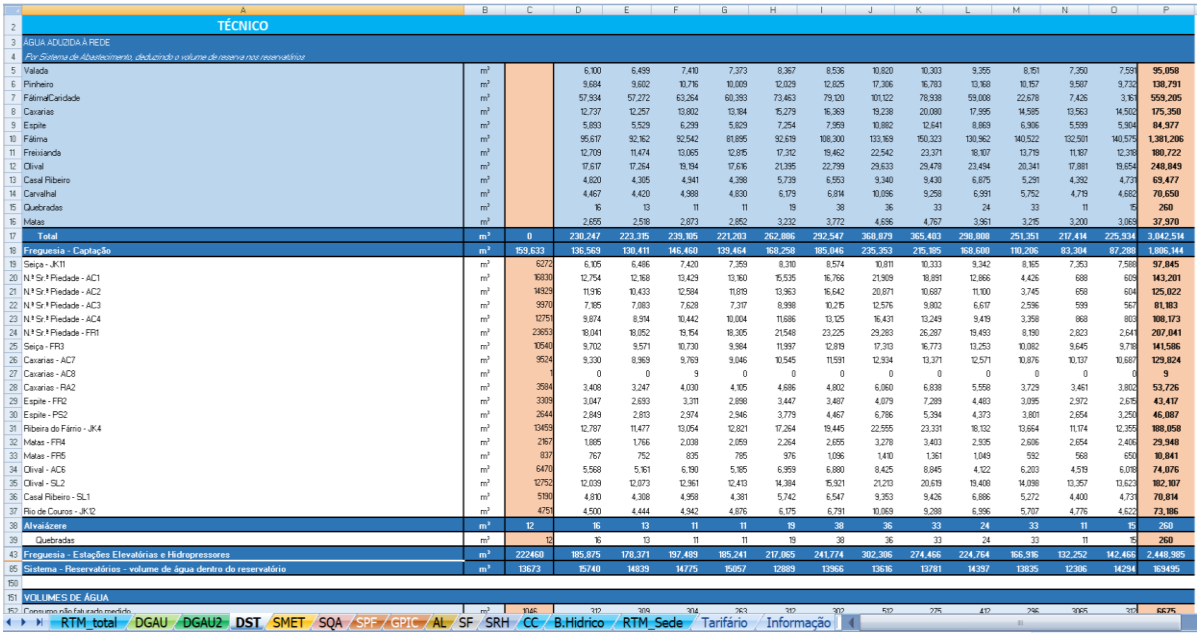
According to Mr. Nuno Martinho, a representative from Be Water – Águas de Ourém, the information related to the functioning, operation, and maintenance of the system is collected, analysed, and presented on a monthly basis to all relevant stakeholders within the company. Much emphasis and attention is given to the quality and reliability of the information, this is done to reproduce a true reflection of the entire operation.

Annually the Portuguese Water and Waste Services Regulation Authority (ERSAR), evaluates the quality of water supply service provided to users, and the initial procedure is to request data to be provided by the water companies. This is done through a standardised reporting template, issued to all water companies to be populated and submitted within a specified period.

Figures 3.20 to 3.36 exemplifies the different areas and elements required by ERSAR, to evaluate the quality of service through assessment and the implementation of performance indicators.

Be Water - Águas de Ourém indicated that due to the structure and comprehensiveness of their internal monthly reports, completing the template is relatively straightforward. Mr. Martinho elaborated further "it's not about the company itself, but it's about the information it gathers, what it means, the influencing factors, and the interlinking of the different elements and how they influence each other".

Figure 3.19 is a summary from the internal monthly report from Be Water – Águas de Ourém, illustrating the volume of water introduced to the system.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
2	TÉCNICO															
3	ÁGUA ADUZIDA À REDE															
4	*Por Sistema de Abastecimento, deduzindo o volume de reserva nos reservatórios*															
5	Valada	m³		6,100	6,499	7,410	7,373	8,367	8,536	10,820	10,303	9,355	8,151	7,350	7,591	95,058
6	Pinheiro	m³		9,684	9,602	10,716	10,009	12,029	12,825	17,306	16,783	13,168	10,157	9,587	9,732	138,791
7	FátimaCaridade	m³		57,934	57,272	63,264	60,393	73,463	79,120	101,122	78,938	59,008	22,678	7,426	3,161	559,205
8	Caxarias	m³		12,737	12,257	13,802	13,184	15,279	16,369	19,238	20,080	17,995	14,585	13,563	14,502	175,350
9	Espite	m³		5,893	5,529	6,299	5,829	7,254	7,959	10,882	12,641	8,869	6,906	5,599	5,904	84,977
10	Fátima	m³		95,617	92,162	92,542	81,895	92,619	108,300	133,169	150,323	130,962	140,522	132,501	140,575	1,381,206
11	Freixianda	m³		12,709	11,474	13,065	12,815	17,312	19,462	22,542	23,371	18,107	13,719	11,187	12,318	180,722
12	Olival	m³		17,617	17,264	19,194	17,616	21,395	22,799	29,633	29,478	23,494	20,341	17,881	19,654	248,849
13	Casal Ribeiro	m³		4,820	4,305	4,941	4,398	5,739	6,553	9,340	9,430	6,875	5,291	4,392	4,731	69,477
14	Carvalhal	m³		4,467	4,420	4,988	4,830	6,179	6,814	10,096	9,258	6,991	5,752	4,719	4,682	70,650
15	Quebradas	m³		16	13	11	11	19	38	36	33	24	33	11	15	260
16	Matas	m³		2,655	2,518	2,873	2,852	3,232	3,772	4,696	4,767	3,961	3,215	3,200	3,069	37,970
17	Total	m³	0	230,247	223,315	239,105	221,203	262,886	292,547	368,879	365,403	298,808	251,351	217,414	225,934	3,042,514
18	Freguesia - Captação	m³	159,633	136,569	130,411	146,460	139,464	168,258	185,046	235,353	215,185	168,600	110,206	83,304	87,288	1,806,144
19	Seiça - JK11	m³	6272	6,105	6,486	7,420	7,359	8,310	8,574	10,811	10,333	9,342	8,165	7,353	7,588	97,845
20	N.ª Sr.ª Piedade - AC1	m³	16830	12,754	12,168	13,429	13,160	15,535	16,766	21,909	18,891	12,866	4,426	688	609	143,201
21	N.ª Sr.ª Piedade - AC2	m³	14929	11,916	10,433	12,584	11,819	13,963	16,642	20,871	10,687	11,100	3,745	658	604	125,022
22	N.ª Sr.ª Piedade - AC3	m³	9970	7,185	7,083	7,628	7,317	8,998	10,215	12,576	9,802	6,617	2,596	599	567	81,183
23	N.ª Sr.ª Piedade - AC4	m³	12751	9,874	8,914	10,442	10,004	11,686	13,125	16,431	13,249	9,419	3,358	868	803	108,173
24	N.ª Sr.ª Piedade - FR1	m³	23653	18,041	18,052	19,154	18,305	21,548	23,225	29,283	26,287	19,493	8,190	2,823	2,641	207,041
25	Seiça - FR3	m³	10540	9,702	9,571	10,730	9,984	11,997	12,819	17,313	16,773	13,253	10,082	9,645	9,718	141,586
26	Caxarias - AC7	m³	9524	9,330	8,969	9,769	9,046	10,545	11,591	12,934	13,371	12,571	10,876	10,137	10,687	129,824
27	Caxarias - AC8	m³	1	0	0	9	0	0	0	0	0	0	0	0	0	9
28	Caxarias - RA2	m³	3584	3,408	3,247	4,030	4,105	4,686	4,802	6,060	6,838	5,558	3,729	3,461	3,802	53,726
29	Espite - FR2	m³	3309	3,047	2,693	3,311	2,898	3,447	3,487	4,079	7,289	4,483	3,095	2,972	2,615	43,417
30	Espite - PS2	m³	2644	2,849	2,813	2,974	2,946	3,779	4,467	6,786	5,394	4,373	3,801	2,654	3,250	46,087
31	Ribeira do Fárrio - JK4	m³	13459	12,787	11,477	13,054	12,821	17,264	19,445	22,555	23,331	18,132	13,664	11,174	12,355	188,058
32	Matas - FR4	m³	2167	1,885	1,766	2,038	2,059	2,264	2,655	3,278	3,403	2,935	2,606	2,654	2,406	29,948
33	Matas - FR5	m³	837	767	752	835	785	976	1,096	1,410	1,361	1,049	592	568	650	10,841
34	Olival - AC6	m³	6470	5,568	5,161	6,190	5,185	6,959	6,880	8,425	8,845	4,122	6,203	4,519	6,018	74,076
35	Olival - SL2	m³	12752	12,039	12,073	12,961	12,413	14,384	15,921	21,213	20,619	19,408	14,098	13,357	13,623	182,107
36	Casal Ribeiro - SL1	m³	5190	4,810	4,308	4,958	4,381	5,742	6,547	9,353	9,426	6,886	5,272	4,400	4,731	70,814
37	Rio de Couros - JK12	m³	4751	4,500	4,444	4,942	4,876	6,175	6,791	10,069	9,288	6,996	5,707	4,776	4,622	73,186
38	Alvaiázere	m³	12	16	13	11	11	19	38	36	33	24	33	11	15	260
39	Quebradas	m³	12	16	13	11	11	19	38	36	33	24	33	11	15	260
43	Freguesia - Estações Elevatórias e Hidropressores	m³	222460	185,875	178,371	197,489	185,241	217,065	241,774	302,306	274,466	224,764	166,916	132,252	142,466	2,448,985
85	Sistema - Reservatórios - volume de água dentro do reservatório	m³	13673	15740	14839	14775	15057	12889	13966	13616	13781	14397	13835	12306	14294	169495
150																
151	VOLUMES DE ÁGUA															
152	Consumo não faturado medido	m³	1046	312	309	304	263	312	302	512	275	412	296	3065	312	6675

Figure 3.19 : Summary from Be Water – Águas de Ourém's monthly report on water volume introduced to the system

3.1.3.1. Human Resources from Water Company

To guarantee a high quality of service, and efficiently functional work environment, the employed number of people in specified working areas, with clearly defined activities is fundamental. Thus, Table 3.3 outlines the data extracted from Figure 3.20 and 3.21, in relation to In-house or Outsourced Human Resources.

This information can be used to substantiate the retention of employees, assess performance management for training & development opportunities, review payroll and financial incentives, and generate a credibility rating for the water company. Furthermore, the planning of health & safety services can use this data to safeguard the interests of both the organization and the employees.

Table 3.3 : In-house and Outsourced Human resources

Fig.	Description	Unit	Section	Required data
3.20	Staff assessing water supply service	Nr.	i	Employee identification, functional area, percentage of water supply allocation, percentage of sanitation allocation, Nr. of months in service and full-time equivalent workers.
3.21	Outsourced personnel to the water supply company	Nr.	ii	Employee identification, functional are, outsourcing activity, methodology, Nr. of workers, Nr. of hours / percentage (%), service provider and, description of the allocation methodology.

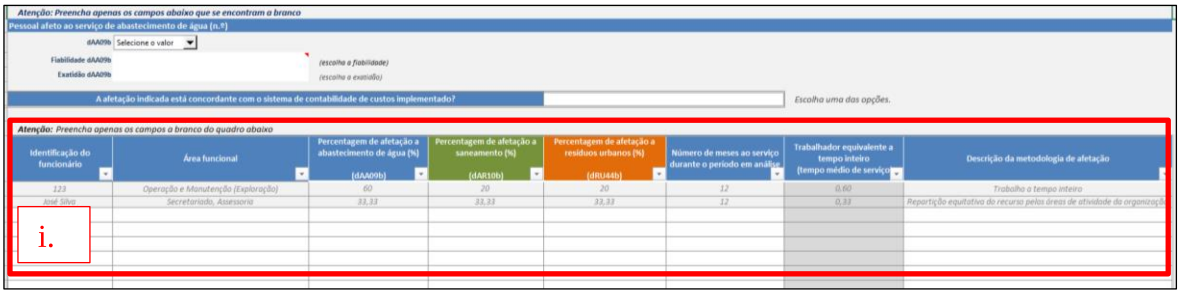


Figure 3.20 : Human Resources

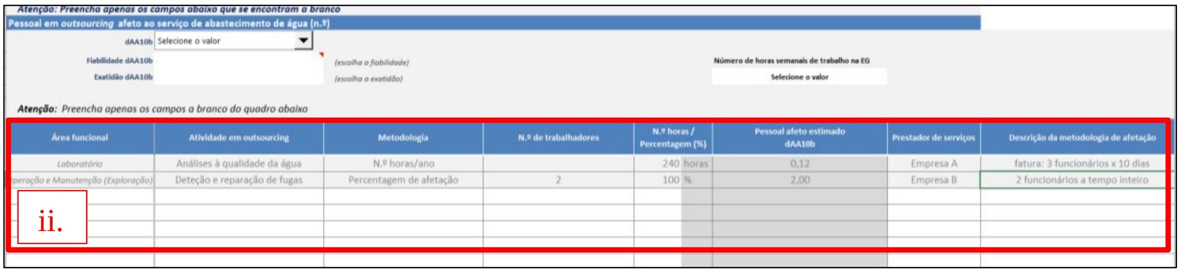


Figure 3.21 : Outsourced Human Resources

3.1.3.2. Accommodation with effective and non-effective services

Information pertaining to accommodations with effective & non-effective service is prudent in identifying the number of users dependent on the services from the water supply company. This data provides a ‘picture’ of the total accommodations within the vicinity and creates an opportunity to investigate sources of water used by accommodations with non-effective services.

Furthermore, this data is fundamental when planning and assessing the demand on the network, establishing the boundaries for asset management infrastructure systems, and identifying unauthorised water consumption. Table 3.4 and Figure 3.22 exemplify the data required, which is also used as an input in the calculation of the national performance indicators ‘Physical accessibility of the service (AA01), and Service subscription (AA07)’.

The number of connecting extensions is used to quantify the performance indicators concerned with ‘Adequacy of human resources (AA11), Occurrence of supply failures (AA03), and Water losses (AA12)’.

Table 3.4 : Accommodation with effective & non-effective services

Fig.	Description	Unit	Section	Required data
3.22	Accommodation with effective service	Nr.	iii.	Name of the municipality and subsystem, total nr. of accommodations with effect and non-effective services on the 31st December of the year in reference, and the Nr. of extensions.
	Accommodation with non-effective service			
	Connecting extensions			

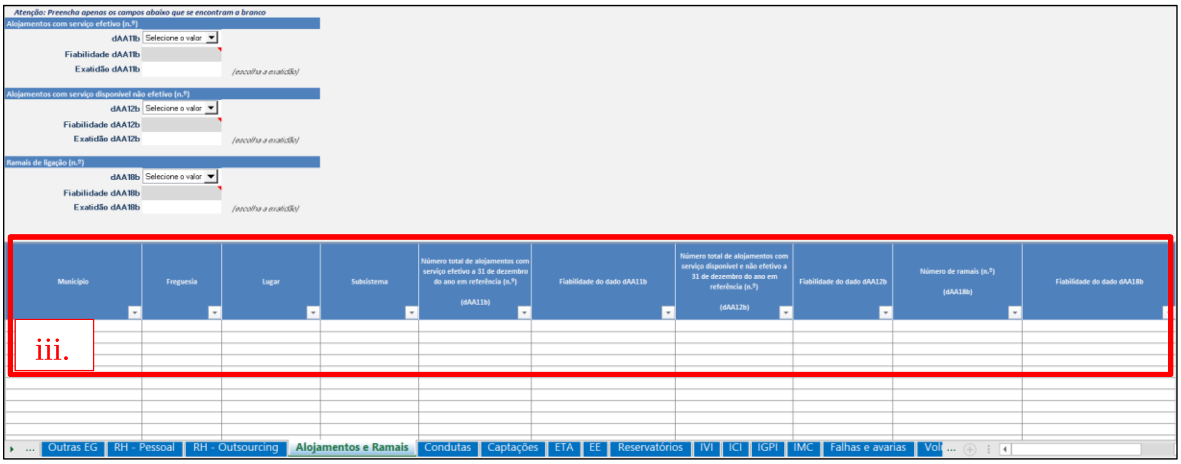


Figure 3.22 : Accommodation and connecting extensions

3.1.3.3. Water Supply Distribution Network

By retaining information such as the year in which the network was constructed and the different timeframes when segments of the pipeline were rehabilitated, the rate of restoration can be calculated. As a result, financial planning, fundraising, and scheduled prioritization is justified. This information is also significant for the operations and maintenance department, enabling anticipated failures, having further insight on pressure limits and quality precautions outside the scope of software and simulations.

For optimum functionality, the network layout, pipe material, fittings and relationship between pressure and flow require expert co-ordination, testing, and approval of hydraulic simulations, including water quality assessments. When isolated from the entire water supply system; the distribution network accounts for majority of water losses, thus routine maintenance, pressure, and asset management are a must. Table 3.5, extracted from Figure 3.23 exemplifies the required data.

Table 3.5 : Water Supply Distribution Network

Fig.	Description	Unit	Section	Required data
3.23	Total length of duct	km	iv.	Name of the municipality and subsystem, total length of pipeline, the year of network construction, material, diameter, technical service life (years), remaining service life, current network value, length of ducts less and more than 10 years, company responsible for rehabilitation and registration Nr. of the intervention.
	Average length of duct			
	Rehabilitated pipelines in the last 5 years			
	Current network value	€		
	Replacement cost			

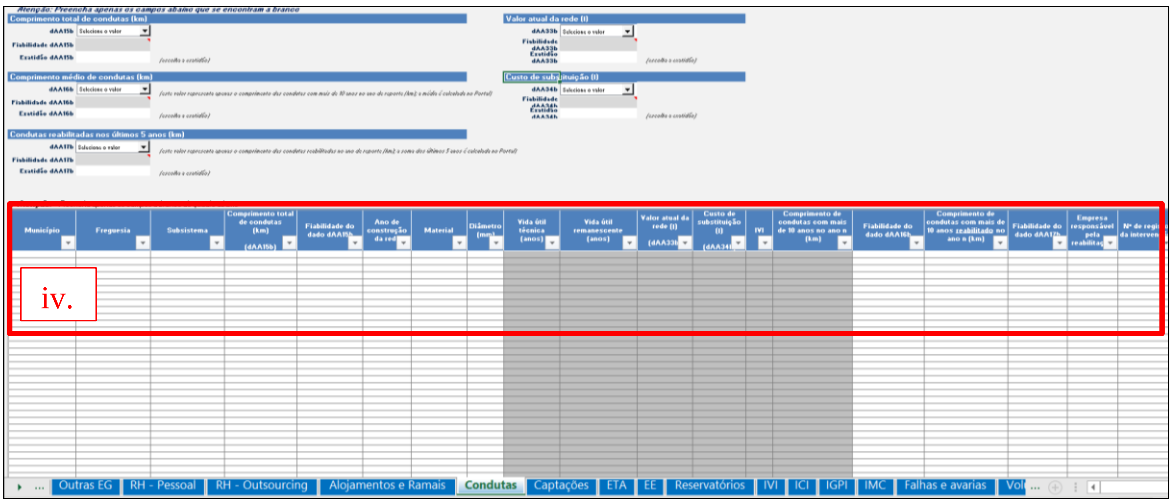


Figure 3.23 : Water Supply Distribution Network

3.1.3.4. Water Catchment

Quantifying, allocating and scaling catchment features correctly enables the efficient use of the resource and protects the environment, resulting in healthy aquatic ecosystems. The data required in Table 3.6, extracted from Figure 3.24; creates a status quo, allowing for better catchment management and input for simulations (e.g., the performance of the catchment after excessive precipitation).

There are several factors that affect water catchment areas (more significantly in aboveground water resources) including, biological, geological, water quality, hydrology & hydraulics and, other barriers.

Furthermore, data on energy requirements, consumption, and own production, assist in indicating the appropriate use of energy resources and determine the average energy consumption for pumping installations.

Table 3.6 **:** Water captured from resource

Fig.	Description	Unit	Section	Required data
3.24	Groundwater catchment nr.	Nr.	v.	Name of the municipality and subsystem, the designation of the catchment and type of capture, the issued date for the use of the water resource, the maximum annual volume defined in the title of use (m3), the date of expiry of the title and the volume of water captured (m3).
	Surface water catchment nr.			
	Water captured in licensed captures	m^3 / year		
	Captured water			
	Energy consumptions for pumping	kWh / year	vi.	Pump manometric height (m), uniformity factor (m3/ year *100m), energy consumption and pumping energy consumption (kWh / year), efficiency test and own energy production (kWh /year).
	Uniformity factor	m^3 / year • 100m		
	Own energy production	kWh/ year		
	Energy consumption			

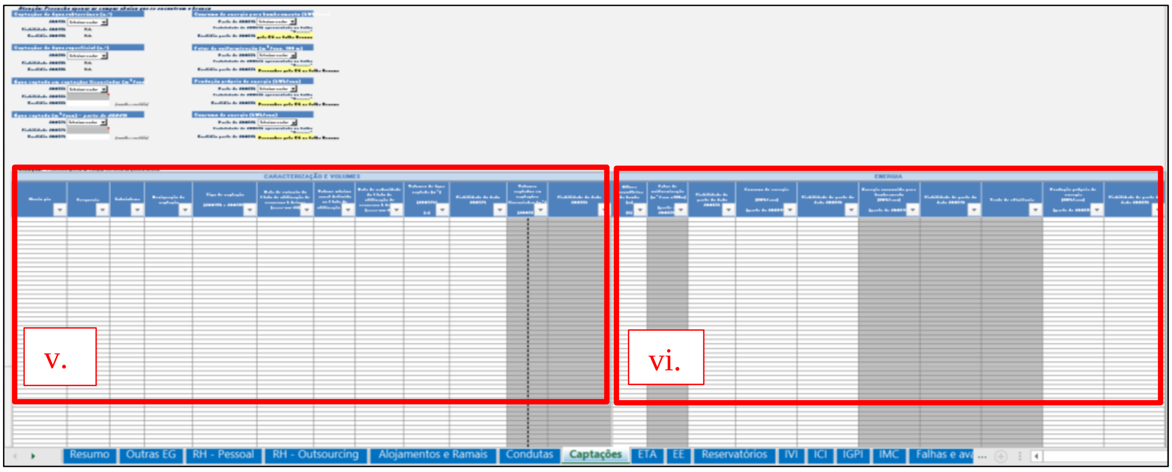


Figure 3.24 : Water captured from resource

3.1.3.5. Water Treatment Station

The integrity of a water treatment facility is dependent on the 4 distinct areas and data require in Table 3.7, extrapolated from Figure 3.25, which identifies the following: The type of installation & processes, the total capacity & operations requirement, energy consumptions, and the disposal & quantity of the sludge.

In the process of producing quality potable water (relative to the resource), operation efficiency and environmental sustainability remain equally paramount. The water treatment at Be Water – Águas de Ourém includes operations of pH regulation, with sodium hydroxide and disinfection using sodium hypochlorite.

Table 3.7 : Water treatment station

Fig.	Description	Unit	Section	Required data
3.25	Water treatment Station	Nr.	vii.	The name of the municipality and subsystem, the type of installation, the installation identification, the coordinates, and the treatment line (liquid phase).
	Other treatment facilities			
	Filling stations			
	Overuse of treatment stations	m^3	viii.	The total capacity of the treatment station (m^3), the over-use and under use of the treatment station (m^3), and the proper use of the treatment station.
	Underuse of treatment stations			
	Proper use of treatment stations			
	Total capacity of treatment station			
	Energy consumption	kWh / year	ix.	The energy consumption and own energy production.
	Own energy production			
	Dehydrated sludge delivered to licensed operator	t / year	x.	The destination of the treatment plant filters washing water, treatment line (solid phase), dehydrated sludge delivered to licensed operator (t/ year), dry sludge delivered to licensed operator (t/ year), dry sludge drained from treatment facilities (t / year), final destination ,Operator identification, License number, tons allowed in license (t)
	Dehydrated sludge drained from treatment facilities			
	Dry sludge delivered to licensed operator			
	Dried sludge drained from treatment facilities			

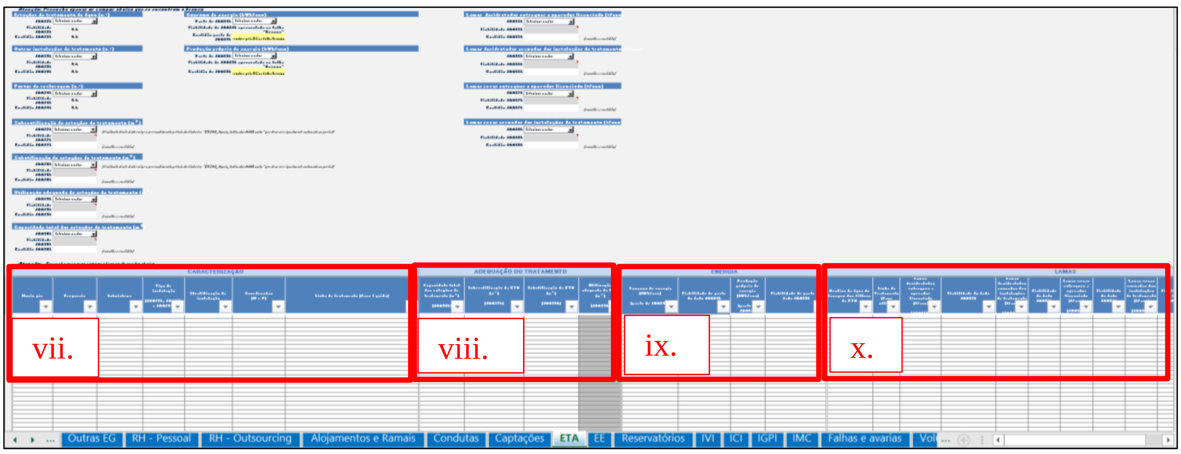


Figure 3.25 :Water Treatment Station

3.1.3.6. Lifting Station & Reservoir

The areas of importance with Lifting Stations and Reservoirs are energy consumption (kWh) and reservoir capacity (m^3). Table 3.8 exemplify the data extracted from Figure 3.26 and 3.27 respectively and required by ERSAR.

Table 3.8 : Lifting station & Reservoir

Fig.	Description	Unit	Section	Required data
3.26	Lift stations	Nr.	xi.	Name of the municipality and subsystem, the lift station identification and installed capacity (m3/h), High annual volume (m3), manometric height (m), uniformity factor (m3 / year • 100m), Energy consumption (kWh /year), energy consumed for pumping (kWh /year), lifting installation efficiency test, own energy production (kWh /year).
	Energy consumption for pumping	kWh / year		
	Uniformity factor	m3 / year • 100m		
	Own energy production	kWh / year		
	Energy consumption			
3.27	Reservoirs	Nr.	xii.	The name of the municipality and subsystem, the reservoir and capacity (m3).
	Water reserve capacity in adduction and distribution	m3		
	Energy consumption	kWh / year	xiii.	The energy consumption (kWh / year), and own energy production (kWh /year).
	Own energy production			

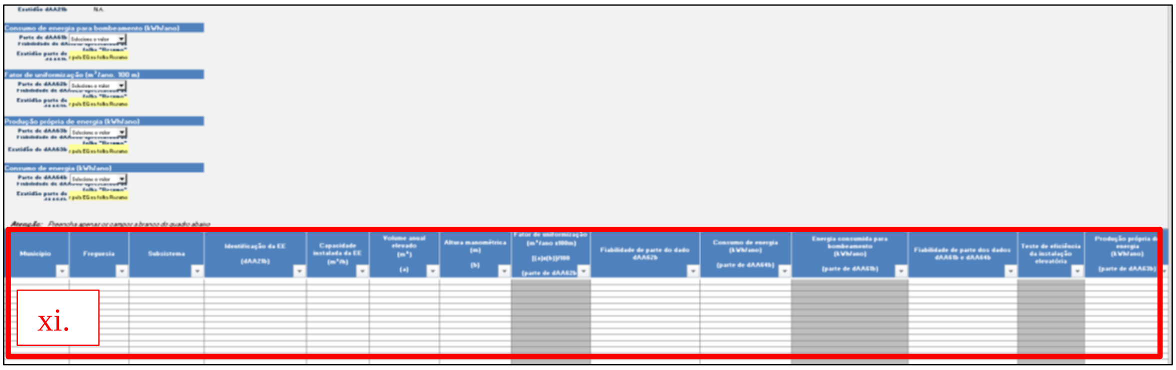


Figure 3.26 :Lifting Station

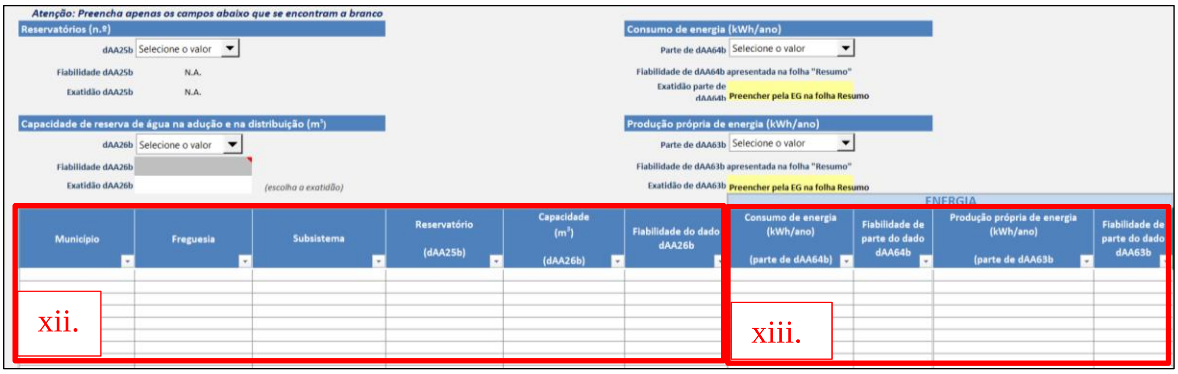


Figure 3.27 : Reservoirs

Furthermore, water levels in both water source & reservoir, pressure and flow are other crucial elements to regularly monitor the operation of a water supply system. Figure 3.28 illustrates a 'mimic diagram' of the installation features from Be Water – Águas de Ourém.

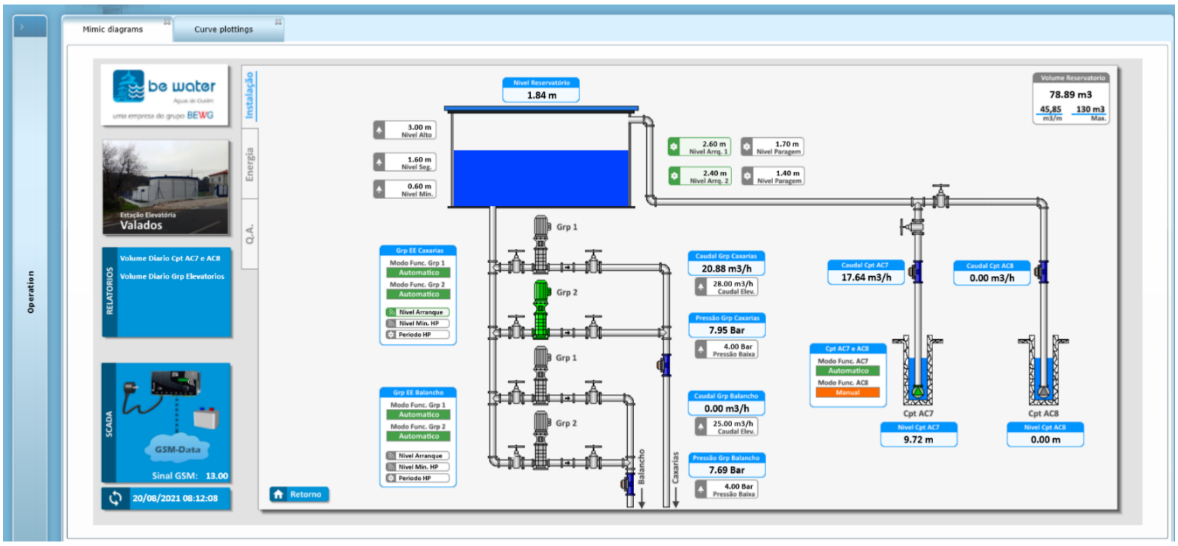


Figure 3.28 : Operational system used at Be Water – Águas de Ourém

The detailed information of all the components produced in 'real time', provides an opportunity to make undoubtably accurate decisions and address technical challenges as soon as they occur. These operations and management systems are the solution to improving the quality of service and efficiency in water supply systems.

3.1.3.7. Infrastructure Knowledge Index

Maximum effectiveness and efficiency are only guaranteed when all the water supply structural features from initial resource to the final product consumed by users work in tandem. The data required in Table 3.9, extracted from Figure 3.29 intends to ensure that all the different structural components are compatible.

The full specifications, operational conditions, and state of conservation of the existing plant, ducts & connecting extensions, measuring equipment, interventions, and the interconnection between GIS and both customer & operational management systems is the principal information required for the Infrastructure Knowledge Index.

Table 3.9 : Infrastructure Knowledge Index

Fig.	Description	Unit	Section	Required data
3.29	Existence of infrastructure plant	N/A	xiv.	Name of the subsystem and length of the duct within the subsystem (under all descriptions), the use of trace mapping or orthophoto cartography, up-to-date information on the location of capture points, water treatment facilities and filling stations, reservoirs, and lifting facilities. (All this information on paper, computer media, GIS and updated for at least 2-5 years).
	Recorded information on ducts and connection extensions	N/A	xv.	Table 3.5
	Recorded information on other infrastructure	N/A	xvi.	Water treatment facility – Table 3.7 Reservoirs – Table 3.8, nr. of cells, and slum & water inlet dimensions Lifting installations – Table 3.8, pump shaft dimensions. The Year / decade of installation and equipment renovations for all featured infrastructure.
	Recorded information on measuring equipment	N/A	xvii.	Location, and description for monitoring equipment (flow meters, pressure, or water quality analysers).
	Registered information on the state of conservation of infrastructure	N/A	xviii.	The state of conservation of the catchment, treatment facilities, lifting facilities, and reservoirs
	Registered information on interventions in the public network	N/A	xix	Network & extension interventions, including location of the component, date of intervention, justification, and description (repair, renewal, etc.) History of interventions & replaced components.
	Interconnection between GIS and other EG information systems and recording of risk factors	N/A	xx	Existence of direct and automatic interconnection between GIS & customer management information systems, and GIS & operations and management Critical components and major risk factors for failure to be recorded.

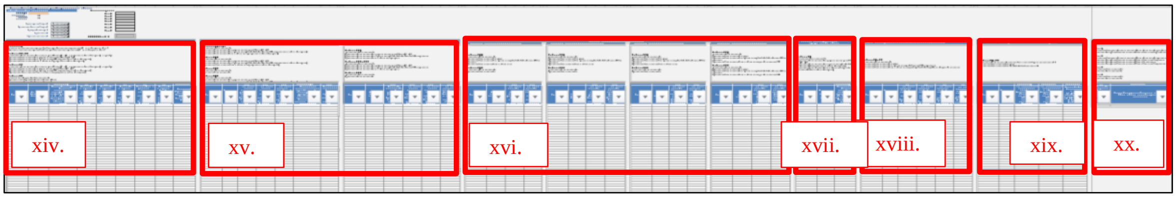


Figure 3.29 :Infrastructure Knowledge Index

3.1.3.8. Flow Measurement Index

The data required from infrastructure measuring equipment is indicated in Table 3.10, which is extracted from Figure 3.30. Accuracy and calibration are additional elements that can be addressed.

Table 3.10 :Flow Measurement Index

Fig.	Description	Unit	Section	Required data
	Measurement in water catchment	N/A	xxi.	The designation of the catchment, annual volume of water captured (m3), and the existence of a measuring point in the capture.
	Measurements at Water Treatment stations	N/A	xxii.	The designation of the treatment station, the annual volume treated (m3), the existence of measuring point at input & exit, and whether it is an entry point into the system.
	Measurements in other water treatment facilities	N/A	xxiii.	
	Measurements in reservoirs	N/A	xxiv.	The designation of the reservoir, the total volume of water in/out of the reservoirs (m3), the existence of a measuring point at the input or output, and whether it is an entry point into the system.
	Measurements at lifting stations	N/A	xxv.	The designation of the lifting station, the high annual volume (m3), the existence of high flow measurement, and whether it is an entry point into the system.
3.30	Measurements in control zones or subsystems	N/A	xxvi.	The designation of the control zone, the length of the subsystem (km), the existence of measurement in the control zones or subsystems.
	Measurements for billing purposes and other water outlets in the system	N/A	xxvii.	The subsystem , the total volume of consumption billed to home users and non-home users (m3/year), volumes billed to domestic users and non-domestic users subject to measurement (m3/year), Total volume of unbilled authorized consumption (m3/year), unbilled authorized consumption subject to measurement (m3/year) , total volume of treated water exported (m3/year) ,volume of treated water exported subject to measurement (m3/year), the existence of a metrological control procedure applicable to all flow meters.
	Measurements at water entry points in the system	N/A	xxiii.	The infrastructure, Annual volume of water measured (m3), and the total annual water volume (m3).

Figure 3.30 : Flow Measurement Index

3.1.3.9. Failures and Breakdowns

The data required in Table 3.11, extracted from Figure 3.31 is extremely essential as any intervention in the water infrastructure may affect customers and their water related activities including industrial, manufacturing, and corporate designated areas. Understanding the nature of the intervention and the amount of time allocated to reinstate the operation of the water supply network is imperative.

In Be Water – Águas de Ourém the accuracy in reporting, reliability and quality of data related to failures and breakdowns is prioritized for transparency. The age of the water supply network is the biggest contributing factor, Figure 3.32 illustrates the network characteristics in one of the subsystems.

Table 3.11 :Failures and Breakdowns

Fig.	Description	Unit	Section	Required data
3.31	Supply failures Duct breakdowns	Nr. /year	xxix.	The name of the municipality and subsystem, the type and date of occurrence, the duration of the failures (hours), whether it was planned and if a notice was given, the reason for the occurrence and the company responsible for the repairs.

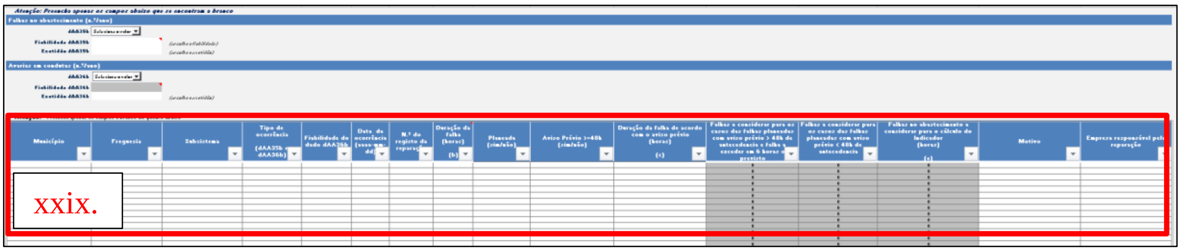


Figure 3.31 :Failures and Breakdowns

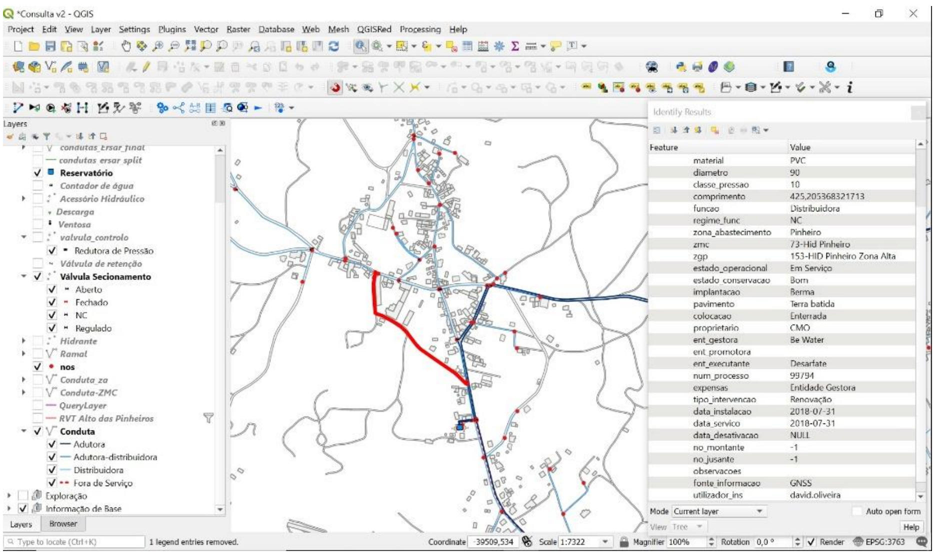


Figure 3.32 : Network Characteristics including age from one subsystem in Be Water – Águas de Ourém

3.1.3.10. Water Volumes

The data required in Table 3.12 and 3.13, extracted from Figure 3.33 consists of water administration and characterisation on a primary and secondary scale. Once ascertained and collaborated, the information can produce the water balance (see Figure 3.34).

Table 3.12 **:** Water volumes I

Fig.	Description	Unit	Section	Required data
N/A	Water entering the system	m^3 / year	N/A	The name of the municipality and subsystem, the designation of the water entry and exit point in the system, annual volume of raw water and treated water imported or exported (m^3).
	Imported treated water			
	Imported raw water			
	Exported raw water			
	Treated water exported			

Table 3.13 : Water volumes II

Fig.	Description	Unit	Section	Required data
3.33	Authorised consumption	m^3/ year	xxxi.	The name of the municipality and subsystem, the type of client, methodology, billed water volume (m^3), Nr. of annual volume measurement taken.
	Measured invoiced consumption			
	Unmeasured invoiced consumption			
	Domestic billed water			
	Non-domestic billed water			
	Billed water			
	Unbilled water	m^3/ year	xxxii.	The name of the municipality and subsystem, the customer designation, methodology, volume of unbilled water (m^3 /year).
	Unbilled Measured consumption			
	Unbilled Unmeasured consumption			
	Unauthorised use	m^3/ year	xxxiii.	The name of the municipality and subsystem, the volume (m^3), and methodology.
	Loss by measured error	m^3/ year	xxxiv.	
	Actual losses			

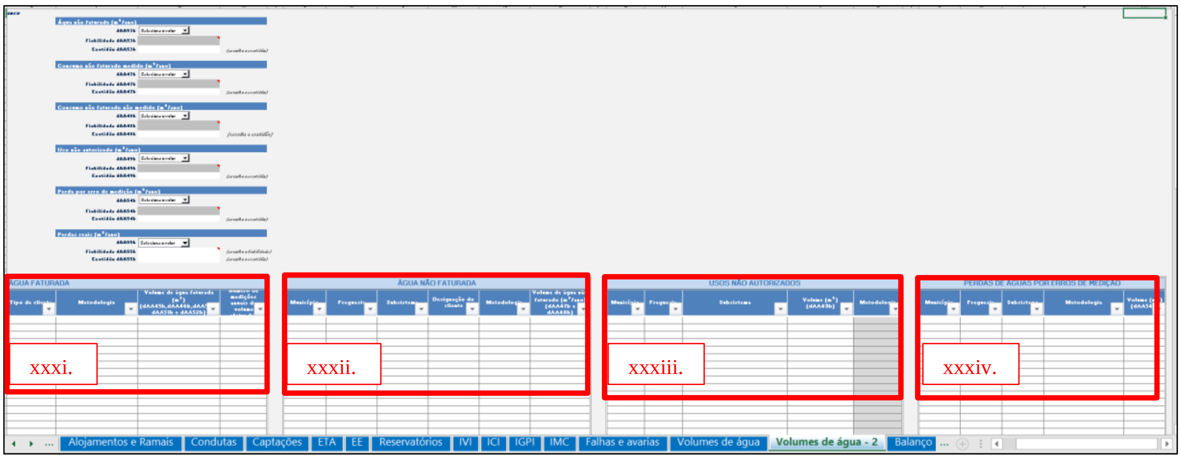


Figure 3.33 : Water Volumes II

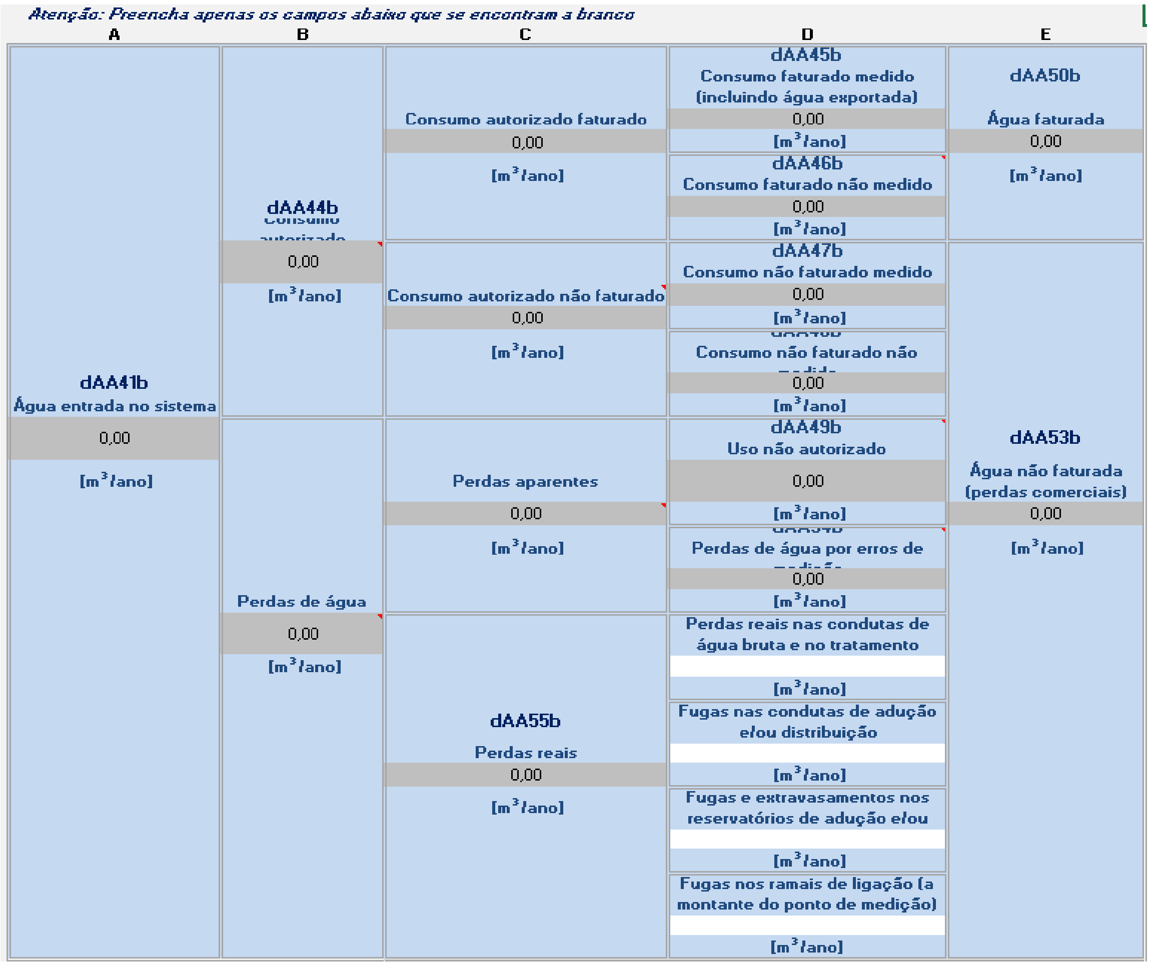


Figure 3.34 :Water Balance

3.1.3.11. Complaints and Responses

Communication between the utility and users establishes a base for change and improvement, hence the data required in Table 3.14, extracted from Figure 3.35 is significant. Complaints can be associated with Billing, Supply Interruptions, Poor Service Delivery, Water quality, Claims or Services. Be Water – Águas de Ourém registered 2 suggestions and 110 complains in 2019, of which 2.73% were considered to be well founded.

Table 3.14 : Complaints and Responses

Fig.	Description	Unit	Section	Required data
3.35	Complaints and suggestions	Nr. /Year	xxxv.	The registration number of the complaint /suggestion, means of communication, subject, date of entry, response date, deadline for reply (working days), and response type (intermediate /end).
	Response to complaints and suggestions			

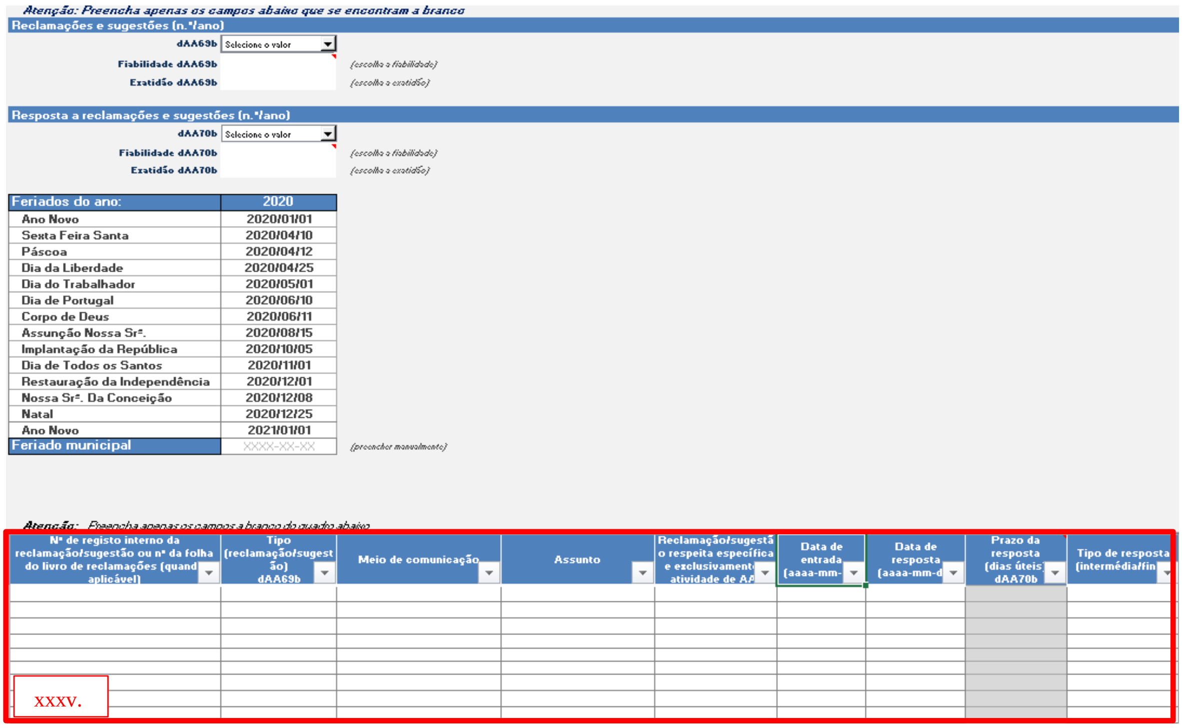


Figure 3.35 :Complaints and Responses

3.1.3.12. Certification and Planning

Attaining certification with regulators and associated institutions improves the organisations prestige and image, increases confidence of workers & customers, and fosters a culture of continuous improvements.

Cooperation and collaboration with requests for information from the Municipality of Ourém, the health authority, APA, INE, ERSAR and other entities were attended to by Be Water – Águas de Ourém; including an audit according to the NP EN ISO 9001:2015, NP EN ISO 14001:2015, and OHSAS18001:2007/NP4397:2008. This took place in May 2019 prioritizing integrated management (environment, quality, and security) by APCER (Be Water - Águas de Ourém, 2019).

Table 3.15, extracted from Figure 3.36 exemplifies the required data in this regard.

Table 3.15 : Certification and Planning

Fig.	Description	Unit	Section	Required data
3.36	Certification of environmental management systems	N/A	xxxvi.	The certification identification, certifying body, date of issue, expiration date, and the scope of certification.
	Certification of quality management systems			
	Certification of safety and health management systems at work			
	Energy certification			
	Asset management certification			
	Other certifications			
	Contingency plan	N/A	xxxvii.	The plan, date of preparation, percentage of accommodation covered, and the scope.
	Energy efficiency plan			
	Water Safety plan			

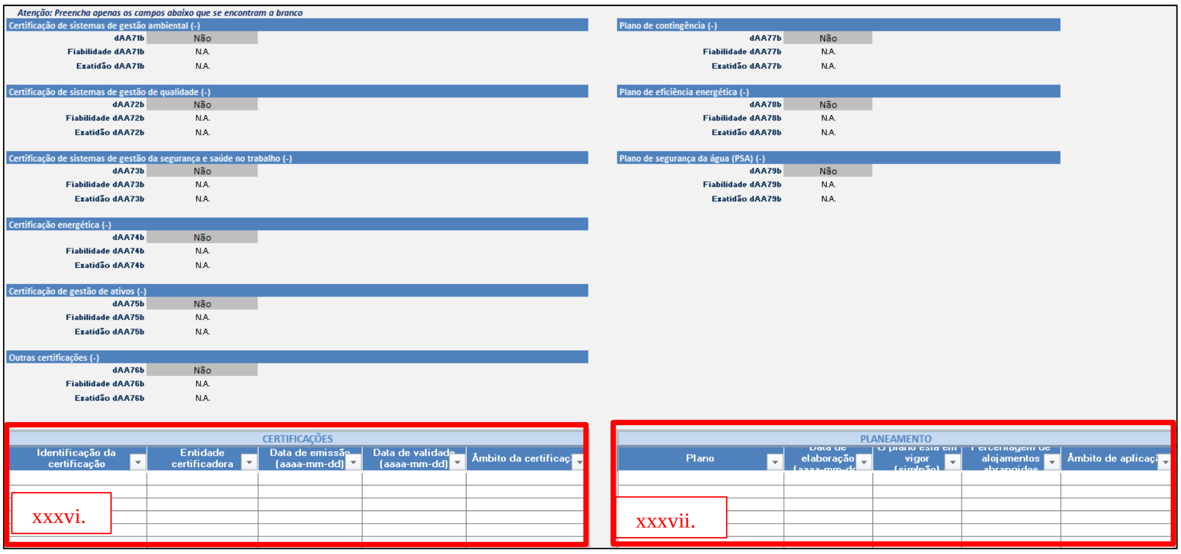


Figure 3.36 :Certification and Planning

4. Conclusion

Population growth and urbanisation have placed tremendous pressure on several services and natural processes, particularly the urban water cycle and urban water supply services. Industrialised countries such as Portugal in particular seem better equipped to continuously adjust and restructure water policies and processes to accommodate the changing environment. This is due to well-developed institutions, sector structures, infrastructure, and a rigorous regulator.

Economically developing countries such as South Africa, which were previously plagued with oppression and inequality are still relentlessly trying to restore balance in institutions, policy, and infrastructure, hence to some degree unable to deal with the pressures of population growth and urbanisation in water services and infrastructure.

Even though encountering different challenges, both countries share a common goal, to consistently improve the quality, availability, efficiency, and affordability of water and water supply services. The presence of performance measuring systems is among the tools used to improve the quality of service in water companies.

In this work, we assessed the application of benchmarking using the 14 Portuguese regulated PIs to determine the quality of service in water companies. The performance of 24 water companies located within the same region and possessing similar characteristics were evaluated over a period of 6 years. The goal was to (1) compute the 14 PIs for each water company and determine the quality of service, (2) benchmark the results from Be Water – Águas de Ourém with the national and cluster averages, and (3) identify Be Water – Águas de Ourém´s position relative to the other water companies within each PI.

Furthermore, an in-depth analysis on the data required from water companies annually by the Portuguese water regulator was examined and its significance discussed.

The advantage and effectiveness of benchmarking and the use of regulated PIs was evident in this work. Through the PIs a status quo was established; whereby Be Water – Águas de Ourém only performed poorly in 3 out of 14 PIs and the 6-year evaluation period was beneficial for assessing performance trends.

The best performing PIs from Be Water – Águas de Ourém’s were Safe water (AA 04), Response to complaints and suggestions (AA 05), and water losses (AA 12). While the poor quality of service was identified under PIs; Occurrence of water supply failures (AA 03), Service subscription (AA 07), and Network rehabilitation (AA 09).

In conjunction to these results Be Water – Águas de Ourém is able to isolate these PIs, assess them in depth individually and also examine their interdependency to understand their dynamics and influences.

Nationally, the PIs that experienced the biggest changes over the 6-year evaluation period were Actual Water Losses (AA 12) which increased by 62.3% between 2014 - 2017 and gradually reduced thereafter, Pipeline Rehabilitation (AA 09) which increased by 46% between 2014 – 2017 and slightly decreasing thereafter, and lastly the occurrence of water supply failure (AA 03) which was reduced by 25% between 2017 -2019.

It is indisputable that the presence of well-structured and regulated performance measuring systems such as benchmarking, and PIs improve the efficiency and effectiveness of water companies. These methods secure continuous advancements in the quality of service and offer water companies an opportunity to identify the ‘best practice’ and evaluate the characteristics, systems, and technologies used to promote operation and management productivity.

The recommendation for future work is to investigate and propose a restructured and well-developed set of performance indicators to be used as the central regulatory performance measurement system in South Africa; inspired by the quality of water supply service evaluation methodology from the Portuguese Water and Waste Services Regulation Authority (ERSAR).

5. Bibliography

Alegre, H., Baptista, J. M., Cabrera, Jr. E., Cubillo, F., Duarte, P., Hirner, W., Merkel, W., & Parena, R. (2006). *Performance Indicators for Water Supply Services* (Second Edition). IWA Publishing.

Alkasseh, J. M. A., Adlan, M. N., Abustan, I., Aziz, H. A., & Hanif, A. B. M. (2013). Applying Minimum Night Flow to Estimate Water Loss Using Statistical Modeling: A Case Study in Kinta Valley, Malaysia. *Water Resources Management*, *27*(5), 1439–1455. https://doi.org/10.1007/s11269-012-0247-2

Angel, S., Parent, J., Civco, Daniel. L., Blei, A., & Potere, D. (2011). *The dimensions of global urban expansion: Estimates and projections for all countries, 2000 - 2050*. *75*(2), 53–107.

Australian Environmental Education. (2019). *The Urban Water Cycle*. WordPress. australianenvironmentaleducation.com.au/education-resources/understanding-the-urban-water-cycle/

Barbier, E. B., & Chaudhry, A. M. (2014). Urban growth and water. *Water Resources and Economics*, *6*, 1–17. https://doi.org/10.1016/j.wre.2014.05.005

Be Water - Águas de Ourém. (2019). *Relatório Anual 2019 Águas de Ourém*.

Be Water Group Limited. (2013). *Be Water - Águas de Ourém*.

Beck, T., Rodina, L., Luker, E., & Harris, L. (2016). *Institutional and policy mapping of the water sector in South Africa*. www.edges.ubc.ca

Berg, S. v. (2020). Performance Assessment Using Key Performance Indicators (KPIs) for Water Utilities: A Primer. In *Revised) Water Economics and Policy* (Vol. 6, Issue 2). www.regulationbodyofknowledge.org

Bhutta, K. S., & Huq, F. (1999). Benchmarking – best practices: An integrated approach. *Benchmarking: An International Journal*, *6*(3), 254–268. https://doi.org/10.1108/14635779910289261

Buhaug, H., & Urdal, H. (2013). An urbanization bomb? Population growth and social disorder in cities. *Global Environmental Change*, *23*(1), 1–10. https://doi.org/10.1016/j.gloenvcha.2012.10.016

Carden, K., & Armitage, N. P. (2013). Assessing urban water sustainability in South Africa - Not just performance measurement. *Water SA*, *39*(3), 345–350. https://doi.org/10.4314/wsa.v39i3.1

Creamer Media. (2012). *Water 2012: A review of South Africa's water sector*.

Demena, M. (2005). *Population and Development*. Haramaya University.

Department of Water Affairs. (2011). *Blue Drop Report ;2011*.

Department of Water Affairs. (2012). *Blue Drop Report ;2012*.

Department of water and forestry. (2001). *Department of water affairs and forestry: Annual Report 2000 - 2001*.

Department of Water and Sanitation. (2013). *Blue Drop Progress Executive Summary 2013*. Department of Water and Sanitation. dws.gov.za/Documents/RSP.aspx

Department of Water and Sanitation. (2014). *Blue Drop Report ; 2014*.

Duarte, V., & Gil, T. (2019). *Portuguese Economy | FOCUS*.

Duranceau, S. J., & Trupiano, V. M. (2011). Evaluation of oxidized media filtration for removing sulfides from groundwater. *Desalination and Water Treatment*, *28*(1–3), 366–377. https://doi.org/10.5004/dwt.2011.2571

ERSAR. (2016a). *Caraterização do Sector de Águas e Resíduos: 2015. vol 1* (Vol. 1).

ERSAR. (2016b). *Caraterização do Sector de Águas e Resíduos: 2016. vol 1*. www.ersar.pt.

ERSAR. (2017). *Caraterização geral do Sector de Águas e Resíduos:2017. vol1*.

ERSAR. (2018). *Caraterização do Sector de Águas e Resíduos :2018. vol 1* (Vol. 1). www.ersar.pt.

ERSAR. (2019). *Caraterização do Setor de Águas e Resíduos: 2019. vol 1*. www.ersar.pt.

ERSAR. (2020). *Guia de Avaliação da qualidade dos Serviços de Águas e Resíduos Prestados aos Utilizadores - 3.ª geração do sistema de avaliação; Série Guia Técnicos 22*.

ERSAR. (2021a). *Caraterização do Setor de Águas e Resíduos: 2020. vol 1*. www.ersar.pt.

ERSAR. (2021b). *Edição: Entidade Reguladora dos Serviços de Águas e Resíduos* (ERSAR, Ed.). www.ersar.pt.

EurEau. (2015). *How benchmarking is used in the Water Sector*. www.eureau.org

European Environmental Agency. (2014). *Performance of water utilities beyond compliance*.

Farley, M., & Trow, S. (2003). *Losses in Water Distribution Networks - A Practitioner´s Guide to Assessment, Monitoring and Control*.

Ferreira Reis, A. C. (2018). *Projeto de Reabilitação para a Valorização do Castelo de Ourém*.

Folifac, F. A. (2007). National Water Policies and Water Services at the extremes: What Challenges must be faced in bridging the gap? Learning from the South Africa Experience. *African Water Journal*, *1*(1), 9–9.

Ganjidoost, A., Knight, M. A., Unger, A. J. A., & Haas, C. T. (2018). Benchmark Performance Indicators for Utility Water and Wastewater Pipelines Infrastructure. *Journal of Water Resources Planning and Management*, *144*(3), 04018003. https://doi.org/10.1061/(asce)wr.1943-5452.0000890

González Villarreal, F., & Lartigue, C. (2017). Performance indicators and perception surveys: a combined assessment of water utilities. In *Water Utility Journal* (Vol. 17). https://www.researchgate.net/publication/329567756

González-Gómez, F., Martínez-Espiñeira, R., García-Valiñas, M. A., & García-Rubio, M. A. (2012a). Explanatory factors of urban water leakage rates in Southern Spain. *Utilities Policy*, *22*, 22–30. https://doi.org/10.1016/j.jup.2012.02.002

González-Gómez, F., Martínez-Espiñeira, R., García-Valiñas, M. A., & García-Rubio, M. A. (2012b). Explanatory factors of urban water leakage rates in Southern Spain. *Utilities Policy*, *22*, 22–30. https://doi.org/10.1016/j.jup.2012.02.002

Güngör-Demirci, G., Lee, J., Keck, J., Guzzetta, R., & Yang, P. (2018). Determinants of non-revenue water for a water utility in California. *Journal of Water Supply: Research and Technology - AQUA*, *67*(3), 270–278. https://doi.org/10.2166/aqua.2018.152

Harris, K., Fellows, C., Quinn, F., Rizk, N., Taylor, N., Whannell, R., Sharma, M., & Taylor, S. (2021). Physical separation techniques in water purification: an inquiry-based laboratory learning experience. *Chemistry Teacher International*, *3*(1). https://doi.org/10.1515/cti-2018-0018

Henriques, A. A., Camanho, A. S., Amorim, P., & Silva, J. G. (2020). Performance benchmarking using composite indicators to support regulation of the Portuguese wastewater sector. *Utilities Policy*, *66*. https://doi.org/10.1016/j.jup.2020.101082

Independent Pricing and Regulatory Tribunal. (2018). *Review of water utility performance indicators*.

Jaladhi, V., Dhruv, B., Utkarsha, K., & Mahroof, M. (2016). Online Performance Assessment System for Urban Water Supply and Sanitation Services in India. *Aquatic Procedia*, *6*, 51–63. https://doi.org/10.1016/j.aqpro.2016.06.007

Kanakoudis, V., & Tsitsifli, S. (2010). Results of an urban water distribution network performance evaluation attempt in Greece. *Urban Water Journal*, *7*(5), 267–285. https://doi.org/10.1080/1573062X.2010.509436

Kingdom, B., Liemberger, R., & Acknowledgements, P. M. (2006). *The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries How the Private Sector Can Help: A Look at Performance-Based Service Contracting*. http://ppiaf.org

Kingdom, B., Liemberger, R., & Philippe, M. (2006). *The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries; How the Private Sector Can Help: A Look at Performance-Based Service Contracting*. http://ppiaf.org

Kohler, H.-P., & Behrman, J. (2015). *Population and Demography: Prioritizing the Post - 2015 UN Development Agenda. The Example of South Africa and Sub-Saharan Africa*.

Lee, J., Lohani, V. K., Dietrich, A. M., & Loganathan, G. v. (2012). Hydraulic transients in plumbing systems. *Water Science and Technology: Water Supply*, *12*(5), 620–629. https://doi.org/10.2166/ws.2012.036

Liemberger, R., & Wyatt, A. (2019). Quantifying the global non-revenue water problem. *Water Science and Technology: Water Supply*, *19*(3), 831–837. https://doi.org/10.2166/ws.2018.129

Lundin, M. (2002). *Indicators fro measuring the sustainability of urban water systems - A Life Cycle Approach*.

Madigele, P. K. (2018). South Africa's water regulatory and policy framework: a new institutional economic review. *Sustainable Water Resources Management*, *4*(1), 129–141. https://doi.org/10.1007/s40899-017-0167-7

Marques, R. C., Gomes, R., Monteiro, A. J., & Pais, A. R. (2005). *Benchmarking the Water Losses in Portugal*.

Marsalek, J., Jiménez-Cisneros, B. E., Malmquist, P., Karamouz, M., Goldenfum, J., & Chocat, B. (2006). Urban Water Cycle Processes and Interactions. In *Urban Water Cycle Processes and Interactions*. CRC Press. https://doi.org/10.1201/9781482288544

Martins, R., & Fortunato, A. (2016). Critical analysis of the Portuguese Water Industry Restructuring Plan. *Utilities Policy*, *43*, 131–139. https://doi.org/10.1016/j.jup.2016.06.014

Masindi, V., & Dunker, L. C. (2016). *State of Water and Sanitation in South Africa*. https://doi.org/10.13140/RG.2.2.11466.77761

Mays, L. W. (2000). *Water Distribution Systems Handbook* (L. . W. Mays, Ed.). McGraw Hill.

McGrane, S. J. (2016). Impacts of urbanisation on hydrological and water quality dynamics, and urban water management: a review. *Hydrological Sciences Journal*, *61*(13), 2295–2311. https://doi.org/10.1080/02626667.2015.1128084

Medrado Cardoso, M. (2019). *Modelos matemáticos de simulação hidrálica como ferramenta de apoio à gestão da pressão em sistemas de distribuição de água: Caso de estudo*.

Melo Baptista, J. (2018). *Lessons learned from water reform in Portugal*. www.lis-water.org

Mendes, M. F., & Magalhães, M. da G. (2011). *Journal of Demographic Studies; No 51-52*.

Mikovits, C., Rauch, W., & Kleidorfer, M. (2014). Dynamics in urban development, population growth and their influences on urban water infrastructure. *Procedia Engineering*, *70*, 1147–1156. https://doi.org/10.1016/j.proeng.2014.02.127

Ministry of Water and Energy. (2013). *Operation and maintenance manual for Urban Water Utilities*.

Mokgope, K., Pollard, S., & Butterworth, J. (2001). *People and systems for water, sanitation and health Water resources and water supply for rural communities in the Sand River Catchment, South Africa*. http://www.nri.org/WSS-IWRM/

Montgomery, Mark. R., Stren, R., Cohen, B., & Reed, H. . E. (2003). *Cities Transformed; Demographic Change and its Implications in the Developing World*. The National Academy Press.

Nations, U., of Economic, D., Affairs, S., & Division, P. (2018). *World Urbanization Prospects The 2018 Revision*.

Neely, A., Gregory, M., & Platts, K. (2005). Performance measurement system design: A literature review and research agenda. In *International Journal of Operations and Production Management* (Vol. 25, Issue 12, pp. 1228–1263). https://doi.org/10.1108/01443570510633639

Ngyende, A. (2011). *Statistical release (Revised)*. www.statssa.gov.za

O'Neill, A. (2021, April 1). *Portugal: Urbanization from 2009 to 2019*. Statista. statista.com/statistics/455915/urbanization-in-portugal/#statisticContainer

Palestine Water Authority. (2011). *Performance Monitoring of Water Service Providers in Palestine*.

Parliamentary Monitoring Group. (2012). Millennium Development Goals : Water and Sanitation. *Millennium Development Goals*, 1–1. https://pmg.org.za/committee-meeting/15046/2/5

Peña-Guzmán, C. A., Melgarejo, J., Lopez-Ortiz, I., & Mesa, D. J. (2017). Simulation of infrastructure options for urban water management in two urban catchments in Bogotá, Colombia. *Water (Switzerland)*, *9*(11), 1–2. https://doi.org/10.3390/w9110858

Rautu, R. S., Racoviteanu, G., & Dinet, E. (2017). Use of Benchmarking for the Improvement of the Operation of the Drinking Water Supply Systems. *Procedia Engineering*, *209*, 180–187. https://doi.org/10.1016/j.proeng.2017.11.145

Rei, A. (2006, January 7). *Geographical location of Ourém*. Wikimedia Commons. commons.wikimedia.org/wiki/File:LocalVilaNovaDeOurem.svg

RSA. (1997). *Water Services Act ; No. 108 of 1997*.

RSA. (1998). *National Water Act ; No 36 of 1998*.

Selowa, S. (2018). *Regulatory Performance Measurement System; Revised Edition of RPMS Concept*.

Seppälä, O. T. (2015). Performance Benchmarking in Nordic Water Utilities. *Procedia Economics and Finance*, *21*, 399–406. https://doi.org/10.1016/s2212-5671(15)00192-6

Shimeles, A. (2010). *Migration Patterns, Trends and Policy Issues in Africa*. www.afdb.org/

Trevor, A., & Duckworth, H. (2002). *Rolllan Aqueducts & Water Supply*. www.ducknet.co.uk

United Nations. (2000). United Nations Millennium Declaration. *Resolution Adopted by the General Assembly*.

United Nations. (2015). *The United Nations World Water Development Report 2015: Water for a sustainable world*. The United Nations Educational, Scientific and Cultural Organization.

U.S Geological Survey. (1984). *National Water Summary 1983 -Hydrologic Events and Issues*.

van den Berg, C. (2014). *The Drivers of Non-Revenue Water How Effective Are Non-Revenue Water Reduction Programs?* http://econ.worldbank.org.

van den Berg, C. (2015a). Drivers of non-revenue water: A cross-national analysis. *Utilities Policy*, *36*, 71–78. https://doi.org/10.1016/j.jup.2015.07.005

van den Berg, C. (2015b). Drivers of non-revenue water: A cross-national analysis. *Utilities Policy*, *36*, 71–78. https://doi.org/10.1016/j.jup.2015.07.005

van Zyl, J., & Water Research Commission, S. (2014). *Introduction to operation and maintenance of water distribution systems* (1st ed.).

Varis, O., & Somlyódy, L. (1997). *Global urbanization and urban water :can sustainability be afforded? 35*(9).

Vilanova, M. R. N., Magalhães Filho, P., & Balestieri, J. A. P. (2015). Performance measurement and indicators for water supply management: Review and international cases. *Renewable and Sustainable Energy Reviews*, *43*, 1–12. https://doi.org/10.1016/j.rser.2014.11.043

WaterDM Demand Management. (2016, October 2). *Urban Water Cycle*. WaterDM Demand Management.