COST ESTIMATION MODELS FOR DRINKING WATER TREATMENT PLANTS IN TURKEY

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ABSTRACT

COST ESTIMATION MODELS FOR DRINKING WATER TREATMENT PLANTS IN TURKEY

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Drinking water treatment plants (DWTPs) are essential for ensuring healthy and safe water. Developing cost curves that considers design flow for both capital (CAPEX) and operation and maintenance (OPEX) costs of DWTPs can be a significant benefit for making informed decisions about pricing and resource allocation. The objective of the thesis is to develop cost curves for CAPEX and OPEX of DWTPs in Turkey. Within the scope of the study, cost data from 42 operational DWTPs in Turkey were considered, adjusting the data to reflect 2022 prices. To facilitate the analysis, the DWTPs were categorized into two groups based on their design flow: small plants (0-25 L/sec) and large plants (25-100 L/sec). Cost curves for CAPEX and OPEX that considers the impact of design flow were then developed using this data. The findings for both CAPEX and OPEX in small and large capacity DWTPs confirmed the economies of scale principle. For small capacity plants, the increase in OPEX and CAPEX followed a polynomial trend. Conversely, cost curves for large capacity plants fallow a linear trend, indicating a more proportional increase in costs with design flow.

The average OPEX for the treatment of 1 m^3 of water was found to be lower in large DWTPs, at 0.095 €. In small capacity plants, the unit OPEX was higher, at an average value of 0.176 €.

On the other hand, the CAPEX for DWTP varies between 165,960 and 1,270,888 € in large capacity plants, while this range varies between 129,359 and 632,272 € in small capacity plants. The average CAPEX of a small capacity plants is 289,950.64 €, while the large capacity plants' CAPEX is 538,125 €.

The total cost was found to vary between 0.087 and 0.119 €/ (m^3 x year) for large capacity DWTPs. For the small capacity plants, the range was 0.154 to 0.291 €/ (m^3 x year).

The developed cost curves can guide informed decision-making by municipalities, ministries, and investors regarding the planning, construction, operation, and maintenance of DWTPs in Turkey. Moreover, these curves can inform pricing strategies for municipalities, ensuring that tariffs are reflective of the actual costs of providing drinking water.

Keywords: CAPEX, OPEX, Total Cost, Drinking Water Treatment Plant, Capacity

ÖZ

TÜRKIYE'DEKI İÇME SUYU ARITMA TESISLERI IÇIN MALIYET TAHMIN MODELLERI

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İçme suyu arıtma tesisleri (İAT'ler) sağlıklı ve güvenli su sağlamak için gereklidir. İçme suyu arıtma tesislerinin hem sermaye (CAPEX) hem de işletme ve bakım (OPEX) maliyetleri için tasarım akışını dikkate alan maliyet eğrileri geliştirmek, fiyatlandırma ve kaynak tahsisi hakkında bilinçli kararlar almak için önemli bir fayda olabilir. Tezin amacı, Türkiye'deki İAT'lerin sermaye ve işletme giderleri için maliyet eğrileri geliştirmektir. Çalışma kapsamında Türkiye'de işletilmekte olan 42 İAT'den elde edilen maliyet verileri değerlendirilerek veriler 2022 fiyatlarını yansıtacak şekilde ayarlandı. Analizi kolaylaştırmak için İAT'ler tasarım akışlarına göre iki gruba ayrıldı: küçük kapasiteli tesisler (0-25 L / sn) ve büyük kapasiteli tesisler (25-100 L / sn). Tasarlanan akışın etkisini dikkate alan CAPEX ve OPEX için maliyet eğrileri ve daha sonra bu veriler kullanılarak geliştirilmiştir. Küçük ve büyük kapasiteli İAT'lerde hem CAPEX hem de OPEX için elde edilen bulgular ölçek ekonomileri ilkesini doğruladı. Küçük kapasiteli tesisler için OPEX ve CAPEX'teki artış polinom eğilimi izledi. Tersine, büyük kapasiteli tesisler için maliyet eğrileri, tasarım akışıyla maliyetlerde daha orantılı bir artışa işaret eden doğrusal bir eğilimdir.

1 m^3 suyun arıtılması için ortalama OPEX'in büyük İAT'lerde küçük tesislere göre daha düşük (0,095 €) olduğu bulundu. Küçük kapasiteli tesislerde OPEX, ortalama 0,176 € değeriyle daha yüksekti.

Öte yandan, büyük kapasiteli İAT'ler için CAPEX 165.960 ile 1.270.888 € arasında değişirken, bu aralık küçük kapasiteli tesislerde 129.359 ile 632.272 € arasında değişmektedir. Küçük kapasiteli tesislerin ortalama CAPEX değeri 289.950,64 €, büyük kapasiteli tesislerde ise ortalama CAPEX değeri 538.125,38 €'dur.

Büyük kapasiteli İAT'ler için toplam maliyetin 0,087 ile 0,119 €/ (m^3 x yıl) arasında değiştiği bulundu. Küçük kapasiteli tesisler için bu aralık 0,154 ile 0,291 € / (m^3 x yıl) arasındaydı.

Geliştirilen maliyet eğrileri, Türkiye'deki İAT'lerin planlanması, inşası, işletilmesi ve bakımı konusunda belediyeler, bakanlıklar ve yatırımcılar tarafından bilinçli karar alma süreçlerine rehberlik edebilir. Ayrıca, bu eğriler belediyeler için fiyatlandırma stratejilerini bilgilendirerek tarifelerin içme suyu sağlamanın fiili maliyetlerini yansıtmasını sağlayabilir.

Anahtar Kelimeler: CAPEX, OPEX, Toplam Maliyet, İçme Suyu Arıtma Tesisi, Kapasite

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LIST OF ABBREVIATIONS

DWTP:	Drinking Water Treatment Plant
O&M:	Operational and Maintenance
CAPEX:	Capital Expenditure
OPEX:	Operational Expenditure
L:	Liter
Sec:	Second
EC:	European Council
Ilbank:	İller Bankası A.Ş.
t:	Time
CAFÉ:	Clean Air for Europe
FRP:	Fiber Reinforced Plastic
V:	Volume
Q:	Flow
CF:	Cost Flow
WWTP:	Wastewater Treatment Plant
MWWTP:	Municipal Wastewater Treatment Plant
€:	Euro
TL:	Turkish Lira
R^2:	Correlation Coefficient
F:	Future Cost
i:	interest rate
n:	year

P:	Present Cost
MF:	Microfiltration
NF:	Nanofiltration
RO:	Reverse Osmosis
UV:	Ultraviolet
m^3:	Meter Cube

CHAPTER 1

INTRODUCTION

Drinking water treatment plants (DWTPs) are plants that make the water taken from water sources suitable for drinking water standards and put it into use. The reasons for the existence and effective functioning of these plants are remarkably diverse with the removal of pollutants from water sources being a primary focus (Boccelli et al., 2007). Natural water sources may contain a range of pollutants, including bacteria, viruses, parasites, chemicals, heavy metals, and organic pollutants. The contamination poses a serious threat as the transmission of waterborne pathogens (bacteria, viruses, parasites) by water (Lin et al., 2022) can cause various diseases. DWTPs play an important role by ensuring that safe and healthy drinking water is obtained by purifying the water from these pollutants. By systematically removing pollutants, water treatment plants contribute significantly to preventing waterborne diseases caused by the transmission of pathogens through water.

Treatment plants can also make drinking water taste and smell better. Substances that could give water a bad taste or odor are frequently removed when treated. Standards and laws governing the quality of drinking water are in place to guarantee that the water is suitable for human use. The water supply is compliant with regulatory criteria thanks to treatment plants that are built to meet or surpass these standards. Drinking water treatment is a process that includes various steps to make water supplied from natural water sources (rivers, lakes, and groundwater) comply with health standards. The steps are aeration, coagulation, flocculation, sedimentation, sand filter, disinfection, and supply (Association & Edzwald, 2010). These steps represent the basic processes used to improve the quality of drinking water and protect human health. However, some plants may use different technologies and procedures depending on the source of the water, local needs, and the quality of the water. There is an undeniable link between the choice of drinking water treatment process and expenses. The cost of water treatment is influenced by the complexity of the treatment process, the quality of the water source, regulatory

requirements, the technology used, and the scale of the treatment plant. Planning a cost analysis is a key step in deciding which treatment processes to use when installing a water treatment plant and determining the operating costs of the plant. Cost analysis is crucial for meeting regulatory requirements, making well-informed decisions, and allocating resources wisely for the long-term provision of clean drinking water. Cost analysis helps to accurately estimate the resources required for the construction, operation and maintenance of treatment plants (Horváthová, 2022). In addition, this is a critical tool for preparing the budget of the project and controlling the operation and maintenance. The installation and O&M of these plants require quite large financial burdens and affect many crucial factors.

The economic aspects of DWTPs are multifaceted and encompass several factors, including infrastructure investment, operational expenditures (OPEX), public health benefits, and economic impacts on communities. Making an assessment and comparing the OPEX and capital expenditures (CAPEX) of DWTPs of municipalities is important. The cost data is essential before the implementation of a water treatment plant for several reasons such as financial planning, resource allocation, option analysis, risk management, and decision-making. However, there is no specific CAPEX or OPEX data available for Turkey that decision-making institutions such as Illerbank or State Hydraulic Works involved in the establishment of DWTPs can use. While there is a demand for tools that can be used for conducting preliminary cost estimates for DWTPs, existing studies on cost analysis focus on wastewater treatment, leaving DWTPs underexplored.

1.1 Objective and Scope of the Thesis

This thesis study aims to develop estimation tools to analyze the preliminary CAPEX and OPEX of DWTPs in Turkey. It involves conducting detailed cost analyses of 42 DWTPs in Turkey, grouped by capacity. Within the scope of this thesis, the DWTPs examined are classified into two sub-categories based on their capacity: those with the capacities ranging from 0 to 25 L/sec, and those with capacities ranging from 26-100 L/sec. Within the scope of the thesis, since the largest plant among the 42 DWTPs selected is 100 L/sec, plants in the range of 26-100 L/sec are evaluated as

large capacity plants. The cost analyses performed will consider the CAPEX and OPEX of the plants separately and will provide insight into the allocation of expense parameters in the total expenditure. In addition, by classifying DWTPs according to their capacity, the study will ensure a closer assessment of expense variations as the plant capacities increase.

In Chapter 2 of this thesis, which consists of five chapters in total, different topics are focused on. Background information about the drinking water standards, the regulations related to these standards are explained. Also, the institutions in Turkey that are related to drinking water, DWTPs' situations in Turkey, and the processes used in DWTPs is presented. In Chapter 3, detailed literature reviews have been conducted on the CAPEX and OPEX of DWTPs. How similar studies were conducted and what topics were focused on are given here. In Chapter 4, how the research is conducted, and how the data is collected and analyzed is explained. It includes details such as research methods, data collection and classification, analysis procedures, and methods used for the evaluation of CAPEX and OPEX. In Chapter 5, the results of the CAPEX and OPEX of the DWTPs, are interpreted, and discussed. The results and conclusions are summarized in the final chapter, Chapter 6.

CHAPTER 2

BACKGROUND

2.1 Drinking Water Standards

Drinking water standards are guidelines set out to ensure people's healthy and safe water consumption (Sayato, 1989). These standards assess the quality of water according to certain parameters and define values that are below or above certain levels.

In this section, information is given about what the necessary standards are for DWTPs, and which institutions in Turkey are conducting studies on this issue.

2.1.1 Regulation on Water Intended for Human Consumption

The purpose of the "Regulation on Water Intended for Human Consumption[1]" is to guarantee the technical and sanitary conditions of water meant for human consumption, as well as the standards of water quality. The concepts and practices for producing, packing, labeling, selling, and inspecting drinking and mineral water are outlined in this regulation. Drinking water, potable water, and mineral water are all included under this regulation. Legislative quality requirements concerning drinking water are given in Table A 1 (Appendix A). However, thermal, therapeutic, and natural mineral water are not covered by this regulation. The European Council (EC)'s "Directive on the quality of water intended for human consumption (98/83/EC)", the "Directive on the approximation of the laws of the Member States relating to the exploitation and marketing of natural mineral waters (80/777/EEC), and the "Directive establishing the list, concentration limits and labelling requirements for the constituents of natural mineral waters and the conditions for

[1] Official Gazette, March 2013, No: 2858

using ozone-enriched air for the treatment of natural mineral waters and spring waters (2003/40/EC)" have all been followed in the drafting of this regulation (*EUR-Lex - 31998L0083 - EN - EUR-Lex*, n.d.).

2.1.2 Regulation on the Quality and Treatment of Drinking Water Supplied

The purpose of the "Regulation on the Quality and Treatment of Drinking Water Supplied[2]" is to provide the principles and quality criteria regarding surface water (such as drainage, stream, lake, pond, dam, sea water) and groundwater (such as well, spring, catchment, tunnel, and gallery) from which drinking water is supplied or planned to be supplied and to determine the treatment classes that need to be determined in order for water to be used as drinking and utility water, the determination of treatment efficiency and the issues related to the project design and operation of DWTPs. Also covers the quality category of the waters in which drinking water is supplied or planned to be supplied, the treatment classes to be applied ccording to the category in which the waters are included, the frequency of sampling and analysis for the parameters to be monitored in these waters, and the issues related to determining the treatment efficiency of DWTPs. The inlet water and outlet water of DWTPs are monitored in accordance with the parameters given in the regulation (in accordance with European standards). The treatment efficiency of these parameters is calculated as a percentage of the treatment for each parameter. If the outlet waters of the DWTP cannot be brought to the drinking water standards contained in the "Regulation on Waters for Human Consumption[3]", the efficiency of the treatment processes is increased by carrying out the necessary revision works at the plant. If the pollution parameter is not included in the "Regulation on Waters for Human Consumption", the values in the relevant headings of this regulation are provided (The Ministry of Agriculture and Forestry, 2019).

[2] Official Gazette, 6 July 2019, No: 30823
[3] Official Gazette, March 2013, No: 2858

2.1.3 Regulation on the Quality of Surface Waters

The purpose of this regulation is to determine, classify, and monitor the biological, chemical, physico-chemical and hydromorphological qualities of surface waters and coastal and transitional waters, to determine the procedures and principles for measures to be taken to protect and achieve good water status, to set out the objectives of using these waters in accordance with the sustainable development goals, considering the balance of conservation use. This regulation covers all surface waters and coastal and transitional waters except the open sea Surface Water Quality Regulation, 2015).

2.2 Institutional Framework for DWTPs in Turkey

The construction and operation of DWTPs in Turkey is usually a shared responsibility between various institutions. These institutions may include municipalities, water and sewerage administrations, private companies, and relevant institutions of the state. Municipalities and water and sewerage administrations usually manage the supply of drinking water and the construction of treatment plants at the local level. These institutions take responsibility for issues such as water supply, treatment, distribution, and infrastructure work. The relevant institutions of Turkey can also take part in issues such as the management of water resources, monitoring water quality, and determining drinking water treatment standards. These can usually be institutions such as the Ministry of Environment Urbanization and Climate Change, Ministry of Agriculture and Forestry, and subunits of the ministries like Ilbank.

- The Ministry of Environment, Urbanization, and Climate Change: Activities are carried out to ensure that everyone has the right to access sufficient, safe, healthy, physically accessible, and affordable water, with support for works such as drilling wells, DWTPs, storage tanks, transmission and promotion lines and laying networks required for water supply.
- Ministry of Agriculture and Forestry: The Ministry of Agriculture and Forestry undertakes different tasks in the construction of DWTPs. Planning

and supervision are one of these tasks. The Ministry participates in the planning processes, determines the appropriate regions for the establishment of DWTPs, and evaluates the suitability of projects. In addition, conducting inspections during the construction of the plants, it ensures that the projects comply with the established standards and regulations.

- General Directorate of State Hydraulic Works (DSI): The DSI is one of the main organizations under The Ministry of Agriculture and Forestry related to the management of water resources and the use of water in Turkey. The State Hydraulic Works is an institution responsible for the planning, design, construction, and operation of projects such as the construction of DWTPs and water supply. Project planning is carried out for the construction of a DWTP. At this stage, factors such as the type and quality of the water source, water consumption rates, treatment process requirements, and the location of the plant are considered. Detailed design and engineering studies are carried out for the DWTP in accordance with the project plan. Following the design stage, the DWTP is built and installed. This process includes activities such as the construction of the structural components of the plant, the installation of treatment equipment, the laying of pipelines, and the satisfaction of other infrastructure requirements of the plant.
- Ilbank: Ilbank is an organization established to finance and support infrastructure projects of local governments and public institutions in Turkey. Infrastructure projects such as DWTPs are also located within the responsibility area of Ilbank. Ilbank provide financing for DWTP projects and support local governments in the planning, design, construction, and operation of these plants. It provide low-interest loans for local governments' drinking water infrastructure projects or offer financial support through grant programs.
- Municipalities and Local Authorities: Municipalities undertake important roles such as planning, construction, operation, and maintenance of DWTPs at the local level. There are different roles in DWTPs. The plant planning and management is one of them. Municipalities make the planning of DWTPs by considering factors such as the evaluation of local water resources, the

analysis of water consumption habits, and the determination of future water needs. In addition, municipalities also carry out processes such as selecting suitable land for the establishment of plants, obtaining the necessary permits, and managing the project. Municipalities manage the construction process of DWTPs and ensure that the plants are built in accordance with technical standards during this process. They also carry out regular maintenance of the plants and meet needs such as repair or renovation of equipment. In this way, it is aimed to ensure the efficient operation of the plants and the continuous provision of water quality.

2.3 DWTPs in Turkey

In Turkey, the adequacy of DWTPs is generally evaluated by local government units and government institutions that provide water supply and treatment services. Although the adequacy of DWTPs in Turkey is generally considered good, this situation may vary depending on regional and local characteristics. DWTPs in different regions of Turkey, especially in large cities, are generally operated in a modern and effective manner. However, smaller settlements may experience some difficulties due to infrastructure and resource limitations (Tiggeloven et al., 2020). According to the database in Ilbank, Turkey hosts 669 DWTPs, with 542 currently operational. Unfortunately, a significant portion of these plants is unable to effectively treat micropollutants due to their conventional design.

In the following two sections, an overview of the processes utilized in DWTPs is given, along with associated costs.

2.4 The Processes Applied in DWTPs

The main purpose of DWTPs is to produce potable water, that is clear, colorless, odorless, with no disease-causing organisms present in it, does not contain harmful chemicals, and does not contain chemicals that are harmful to health and the house (for washing clothes or dishes, cleaning, etc. it is a suitable water production to be used for purposes). However, their processes and capacities depend on population,

the properties of raw water as well as on the desired properties in the treated water. (Akgiray et al., 2003)

There are elements that need to be considered regarding the establishment of DWTPs, meeting the general needs of these plants, design, construction, operation, maintenance-repair, and equipment needed during the preparation of control buildings (Committee, 1982). Source water assessment is one of them. Firstly, potential water sources, such as rivers, lakes, groundwater, or reservoirs identified and assessed. Then, evaluation of the quantity of the source water is necessary for the plant capacity and source water quality evaluation for choosing appropriate treatment processes and desired water quality standards. Common treatment methods include coagulation, flocculation, sedimentation, filtration, disinfection (chlorination, UV, ozone), and more. After that with respect to the process of optimizing energy usage to reduce OPEX and environmental impact. This may involve using energy-efficient equipment and considering renewable energy sources. Since CAPEX and OPEX are important cost parameters for operators, developing a comprehensive budget that includes CAPEX for construction and ongoing OPEX.

The choice of process is important in DWTPs because this choice is a critical step that ensures that drinking water is provided to the consumer in a safe and healthy way (Baruth et al., 2005). Some of the reasons for the correct process selection are as follows (Kawamura, 2000). The correct process selection affects water quality (Logsdon et al., 1999). The quality of drinking water is of critical importance for consumer health. Moreover, the correct process selection helps to improve the appearance, taste, and smell of water, as well as effectively remove pollutants, toxins, and pathogens. Water treatment processes are also important for the protection of natural resources and environmental sustainability. Incorrect process selection can increase waste production and lead to environmental impacts. Finally, of course, the cost. The operation and maintenance of DWTPs can be costly. The correct process selection can increase the efficiency of the plant and reduce operating costs. In addition, because of incorrect process selection, the treatment plant may have to be constantly malfunctioning or updated, which may lead to extra costs (Çakmakcı et al., 2013).

With the process description given in detail in Figure 1, the necessary project design criteria are defined with a flow chart for the DWTP (Association & Edzwald, 2010). The source can contain physical and chemical pollutants such as turbidity, color, odor, coliform-separated substances, and organic matter, as well as microbiological pollutants. According to the raw water source of physical, chemical, and microbiological analysis results, after the drinking-water treatment plant, water should be drinkable. In addition, DWTP should be adaptable to the long-term changes in raw water quality.

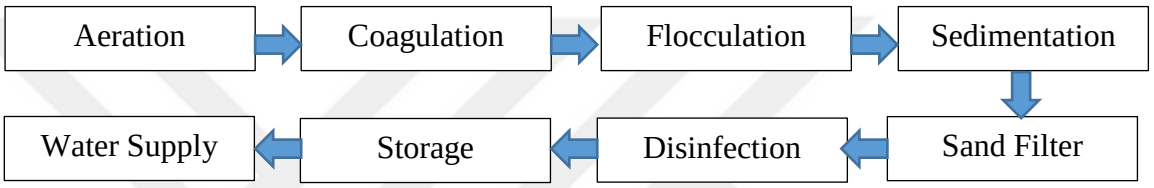

Figure 1. Water Treatment Plant Flow Chart (Association & Edzwald, 2010)

If the water does not include an extra pollutant like arsenic or heavy metals, the processes are the same for all of them. As seen in Figure 1, in Turkey, DWTPs start with an aeration process. Then the aerated water flows into the chemical treatment unit of the plants where coagulation and flocculation occur. During coagulation, a coagulant is introduced to facilitate the agglomeration of colloidal particles. Through chemical reactions between the coagulant and the alkalinity in the water, pollutants and added chemicals promote the formation of flocs. These flocs are then allowed to settle in the sedimentation tank, with the clarified water taken from the top of the sedimentation basin. Following sedimentation water flows to the sand filters to remove particulate matter escaping from sedimentation. Subsequently, the water undergoes a disinfection process to eliminate bacterial pollutants before being distributed as treated water. In the following sections, the processes commonly applied in water treatment plants are described.

2.4.1 Aeration

Aeration in water treatment involves the introduction of air into water to introduce oxygen into water and to promote various physical and chemical processes. It is one of the oldest processes used in water treatment (Aeration for Municipal Water Treatment, n.d.). In this process, a contact surface is established between air and water, allowing the transfer of volatile substances into water or from water. The dissolved oxygen content of water is increased by transferring it from the gas phase to the water phase. Among the most important purposes of aeration units in DWTPs are the oxidation of dissolved iron (Fe^{2+}) to insoluble iron (Fe^{3+}) and the oxidation of dissolved manganese (Mn^{2+}) to insoluble manganese dioxide (MnO_2). Oxidized iron and manganese form precipitates and then removed from water through subsequent sedimentation or filtration processes. The removal of undesirable gases such as methane and hydrogen sulfide from water is another objective in aeration. This helps control odors originating from hydrogen sulfide. Also achieved in aeration is the removal of carbon dioxide from water which may contribute to the adjustment of pH levels and the elimination of volatile compounds that may cause unpleasant odors.

Cascade aeration or stepped aeration that consists of a series of steps or trays through which water flows is the most preferred type of aeration in DWTPs (Khalifa et al., 2011). Because this method offers an effective way to oxygenate reduced substances in water and to remove pollutants. In addition, cascade aeration systems do not contain complex mechanical equipment, and therefore their maintenance requirements are lower. Moreover, cascade aeration can reduce chemical additives to improve the quality of water. These are some advantages of cascade aeration, which help to reduce operating costs and minimize the environmental impact. Figure 2 shows the cascade aerators with four steps. The reason why it is widespread is that it is not using energy. Only the gravitational energy and the potential energy of the water caused by the height are used.

Figure 2. Cascade (ladder) type aerators (Boyden et al., 1992)

Aeration units in water treatment plants contribute to both CAPEX and OPEX. The CAPEX is associated with the design and installation of aerators (construction of the concrete structure and related mechanical equipment) whereas the operation and maintenance costs are related to regular maintenance, including inspections, repairs, and replacement of components and labor. In some water treatment plants, pumping energy may also be required, but the need for it will vary from application to application.

2.4.2 Coagulation and Flocculation

They are structures in which chemical substances are mixed into untreated water, uniform distribution is made, and floc formation occurs. As can be seen in Figure 3, it is possible to provide the mixture mechanically or hydraulically. However, since the efficiency of the mixture is related to the turbulence created, maximum turbulence should be ensured with minimal power consumption. The coagulation process is made in a tank that is made of carbon steel, stainless steel, FRP, etc. in accordance with the design criteria of a reinforced concrete tank or project (Ilbank, 2013). Chemical cost and energy are the most important OPEX items in these two tanks. The most common coagulants that are used in coagulation are aluminum sulfate ($Al_2(SO_4)_3$), ferric sulfate ($Fe_2(SO_4)_3$), and poly aluminum chloride. Moreover, sodium hydroxide and anionic polyelectrolyte are necessary. Sodium

hydroxide is used for pH optimization since the efficiency of the unit will depend on the pH. Anionic polyelectrolyte is a flocculant type that is used for the precipitation of inorganic suspended solids to be used as a solidifier directly before the filter process.

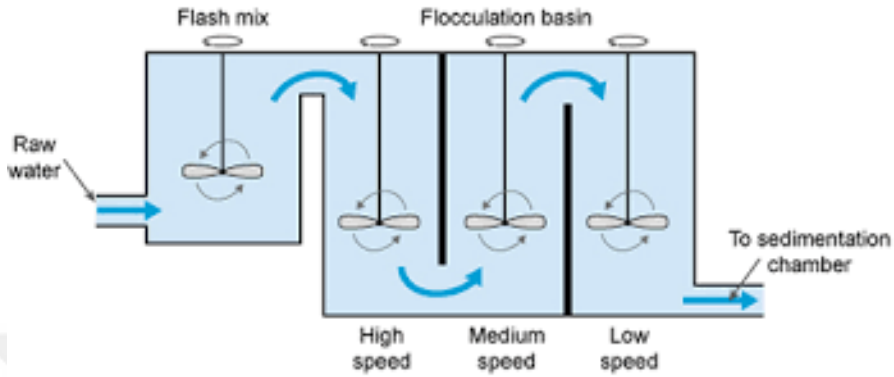

Figure 3. Coagulation and flocculation process diagram (Bratby, 2006)

Numerous variables, such as the kind of coagulants and flocculants employed, the treatment plant's size and capacity, the properties of the water supply, and the state of the local economy, can affect the cost of coagulation and flocculation in water treatment plants.

In water treatment plants, the most used coagulants are inorganic aluminum-based and iron-based compounds. These coagulants are cheaper than organic coagulants. Not only the type of coagulant but also the amount of coagulant required which is influenced by the characteristics of the water being treated, including turbidity, organic matter content, and particle size, contribute to the cost. In general, waters with very low turbidities require higher dosages and therefore are associated with higher OPEX. Energy costs associated with the mixing and application of coagulants and flocculants are the second important OPEX. Labor costs for system operation and maintenance, chemical delivery, handling, and storage are the other OPEX items. Investments in automation and control systems for precise chemical dosing can optimize efficiency.

Larger water treatment plants typically have higher CAPEX due to the need for larger infrastructure, including coagulation and flocculation tanks, mixers, and associated

equipment.

The CAPEX of coagulation and flocculation is mainly determined by the costs associated with the design and installation of coagulation and flocculation tanks, chemical feed systems, including pumps, pipelines, dosing equipment, and chemical storage plants. Other cost items contributing to the total CAPEX are the labor costs associated with the construction and installation of coagulation and flocculation infrastructures.

2.4.3 Sedimentation

The water passing through the sluice from the slow mixing structure enters the clarifier tank. Clarifier tanks, also known as sedimentation tanks or settling tanks, are an essential component in DWTPs. These tanks play a crucial role in the purification process by removing suspended solids, colloidal particles, and other impurities from the raw water.

There are several different types of clarifiers or sedimentation tanks used in water treatment processes. Some of the common types include rectangular clarifiers, circular clarifiers, inclined plate settlers, tube settlers, and lamella clarifiers which is shown in Figure 4 (Voutchkov, 2017).

The primary function of clarifiers is sedimentation. When untreated water enters the tank, the flow velocity is reduced significantly, allowing suspended particles and impurities to settle down under the influence of gravity. As the water remains stationary in the clarifier tank, heavier particles settle to the bottom of the tank, forming a layer of sediment called sludge. Lighter particles and impurities may also settle at a slower rate or form a floating layer on the water surface. The settled particles are then removed from the bottom of the tank through a sludge collection mechanism. The clarified water, which is now substantially free of suspended solids and impurities, rises to the top of the tank and is collected from the overflow weir or launder system. This clarified water undergoes further treatment processes such as filtration and disinfection before it is deemed safe for drinking.

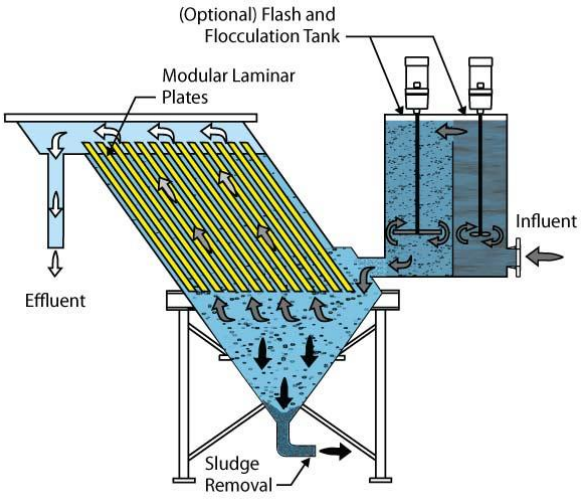

Figure 4. Lamella type sedimentation tank flow diagram (Veljkovic & Mitrovic, 1997)

Overall, clarifier tanks play a critical role in the drinking water treatment process by facilitating the removal of suspended solids and impurities, resulting in clearer, safer water for consumption.

The expenses of sedimentation tanks are equipment costs, installation costs, chemical costs, energy costs, sludge disposal costs, and replacement-repair costs. These expenses in DWTPs are determined by a number of factors. These factors may include various elements such as the design of the plant, operating conditions, environmental impacts, and the treatment technologies used. The factors that make up the operating expenses can be numerous. One such factor is the use of chemical additives aimed at reducing labor costs. Chemical additives are used in some cases to improve the precipitation process and effectively separate sediments. Costs associated with these chemicals may arise from the purchase, storage, and dosage control of these chemicals. Another significant expense is energy consumption. Energy is required to operate the settling tanks like pumping systems, mixers and other equipment consume electricity, which increases energy expenses. On the other hand, CAPEX is material costs which of the cost of materials used in the construction of settling tanks is a big factor. The choice of materials such as concrete, steel, and fiberglass may vary depending on the requirements and budget of the project. Equipment costs (the cost of the equipment required for settling tanks) may vary

depending on the characteristics and capacity of the tank. These equipment may include mixers, pumping systems, inlet/outlet valves and sensors.

2.4.4 Sand Filtration

The process of moving water through a porous media is known as granular filtration. Figure 5 illustrates a typical sand filter, which operates as a granular filtration system. Physical, chemical, and in some cases biological improvements in water quality are obtained during this procedure, such as maintaining suspended and colloidal substances in the water, reducing the number of bacteria and other microbes, and assuring the oxidation of organic molecules (Fujioka et al., 2019). Sand filters are classified based on various factors: filtration rate, driving force, and filter material. They can be classified as slow sand filters or rapid sand filters according to the filtration rate; gravitational or pressurized filters based on driving force; and single-medium or multi-medium filters depending on the filter material.

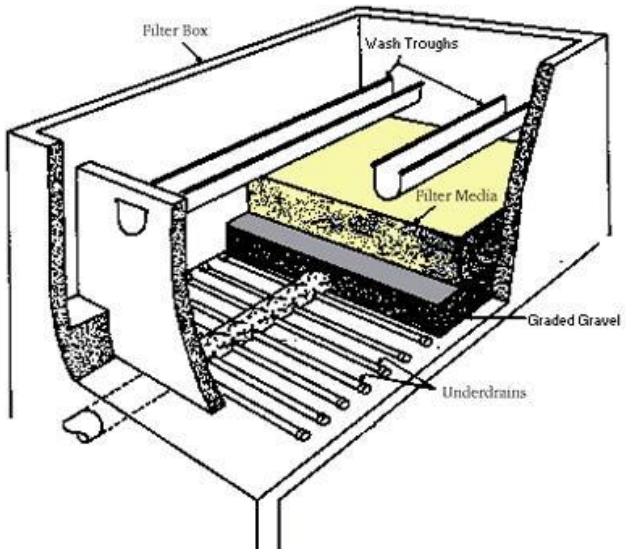

Figure 5. Sand filter diagram (Association & Edzwald, 2010)

Conventional gravity filtration structure costs are based on the use of cast in place concrete with a media depth of 60 to 100 cm and a total depth of 5 m for the filter box. Typical CAPEX for sedimentation units are excavation and field works, equipment, and building materials (concrete, steel, etc.) costs. On the other hand,

operating expenses are filter media (the cost of the filter media used in the filtering process is important. Different plants may prefer different filter media, for example, sand, activated carbon, anthracite coal, etc.), filter tank material and structure (the material and structure from which filters are constructed can have an impact on durability and maintenance requirements. For example, stainless steel filter tanks are usually more durable, but at a higher cost), backwashing system (the filters may become clogged after a certain period, and in this case, the backwashing process is performed. The amount of water used for the backwash system and energy costs may affect the operating cost), maintenance, and repair expenses.

2.4.5 Membrane Filtration

Membrane filtration is a widely used technology in drinking water treatment processes. It involves the use of semi-permeable membranes to separate impurities and contaminants from water, producing clean and safe drinking water. There are several types of membrane filtration processes employed in drinking water treatment, including microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). Each process has its unique characteristics and applications (Smol,2018).

- MF: MF removes particles as small as 0.1 microns, including sediment, dirt, rust, and other suspended solids. These particles can affect the taste, odor, and appearance of water, so removing them is crucial for providing clean and aesthetically pleasing drinking water (Charcosset,2012). It can effectively remove bacteria, protozoa, and some viruses from water. These microorganisms can cause various waterborne diseases such as cholera, typhoid, and giardiasis. By eliminating them, MF helps ensure that drinking water is safe and free from harmful pathogens. MF membranes prevent the growth of biofilms and the accumulation of organic matter on filtration surfaces. This helps maintain the efficiency of the filtration process over time and reduces the need for frequent membrane cleaning or replacement. MF is often used as a pre-treatment step for other drinking water treatment processes such as RO and UF. By removing larger particles and

microorganisms, MF helps protect downstream equipment and membranes, prolonging their lifespan and reducing maintenance costs.

- UF: UF membranes have small pore sizes, typically ranging from 0.01 to 0.1 microns, which effectively remove bacteria, viruses, and protozoa from water. This capability is crucial for ensuring the safety of drinking water by preventing waterborne diseases. UF membranes can remove suspended solids, colloids, and large molecules from water. This includes substances like silt, clay, organic matter, and certain chemicals, improving the clarity and quality of drinking water. UF provides consistent water quality by removing contaminants at a high level of efficiency. This consistency is essential for meeting regulatory standards and ensuring that consumers receive safe and reliable drinking water. UF is often used as a pre-treatment step for RO systems in DWTPs. By removing larger particles and microorganisms, UF helps protect RO membranes from fouling and extends their lifespan, leading to more efficient and cost-effective operation. UF requires minimal or no chemical additives for operation, reducing the environmental impact of water treatment processes. This aspect aligns with the growing emphasis on sustainable and eco-friendly water treatment practices (Singh & Hankins, 2016)
- NF: NF membranes have smaller pore sizes than those of MF and UF but larger than those of RO. This enables NF to selectively remove specific contaminants such as divalent ions (e.g., calcium, magnesium), organic matter, and certain micropollutants while allowing smaller ions and molecules to pass through. This selective removal can significantly improve the taste, odor, and overall quality of drinking water. NF is effective in softening water by removing hardness-causing ions such as calcium and magnesium. Hard water can cause scale buildup in pipes and appliances, decrease soap efficiency, and affect the taste of water. NF helps alleviate these issues by reducing water hardness, resulting in softer and more palatable drinking water. NF can effectively reduce color and turbidity in drinking water by removing dissolved organic compounds and colloidal particles. This improves the aesthetic quality of water, making it clearer and

more visually appealing to consumers. NF can target and remove precursors of disinfection byproducts (DBPs), which are formed when disinfectants like chlorine react with organic matter in water. By reducing the concentration of these precursors, NF can help minimize the formation of potentially harmful DBPs in treated drinking water (Singh & Hankins, 2016).

- RO: RO membranes have extremely small pore sizes, typically in the range of 0.0001 microns, which allows them to effectively remove a wide range of contaminants from water. These include dissolved salts, heavy metals, pesticides, herbicides, pharmaceuticals, and other organic and inorganic substances. It can produce water of exceptionally high purity, meeting stringent drinking water standards. It is highly effective in desalinating seawater and brackish water, making it a crucial technology for providing drinking water in regions facing water scarcity or relying on saline water sources. By removing salts and other dissolved solids, RO produces fresh, potable water from otherwise unusable sources, thus expanding water supply options in arid and coastal regions. It removes dissolved minerals and organic compounds that can contribute to unpleasant tastes and odors in water. By producing water of superior taste and odor quality, RO enhances consumer satisfaction and encourages higher water consumption, promoting better hydration and health. It enables the efficient utilization of water resources by recycling and reusing wastewater or brine generated from the treatment process. This not only reduces the discharge of pollutants into the environment but also conserves freshwater resources by maximizing water recovery and minimizing waste. These systems are versatile and scalable, making them suitable for various applications ranging from small residential units to large municipal water treatment plants. They can be customized to meet specific water quality requirements and production capacities, offering flexibility in system design and implementation (Singh & Hankins, 2016).

2.4.6 Disinfection

Disinfection is the process of destroying or inactivating pathogenic organisms in water to make it safe for drinking, cooking, and other domestic uses. It serves as the last line of defense against waterborne diseases, protecting consumers from potentially harmful contaminants (White,1986).

Chlorination is one of the most used methods of disinfection in DWTPs. Chlorine, in the form of chlorine gas, sodium hypochlorite, or calcium hypochlorite, is added to the water to kill bacteria, viruses, and other microorganisms. In addition to chlorination, other disinfection methods such as UV irradiation, ozonation, and chloramine disinfection are also employed in water treatment plants to ensure effective pathogen removal.

The choice of disinfection method depends on various factors including the characteristics of the site, the characteristics of the raw water source, operational requirements, cost, and operational considerations. All these factors must carefully evaluate to select the most appropriate disinfection method for each DWTP. Another consideration is the removal of some resilient microorganisms, such as Cryptosporidium and Giardia. These microorganisms may require special consideration in the selection of the appropriate disinfection method (Hoff & Akin, 1986).

Chlorination is typically added to the water after primary treatment steps such as coagulation, flocculation, sedimentation, and filtration. The dosage of chlorine required for effective disinfection depends on factors such as the concentration of organic matter and microorganisms in the water, temperature, pH, and contact time. The chlorine dosage to be applied should be closely controlled to achieve the desired level of disinfection while minimizing the formation of disinfection by-products. Following the addition of chlorine to the water, it needs to be thoroughly mixed to ensure uniform distribution and contact with all pathogens. Then, the water is allowed to remain in contact with the chlorine for a specified period, known as the contact time. This allows sufficient time for the chlorine to react with and kill the microorganisms present in the water. To guarantee sufficient disinfection has been

attained and to verify that a sufficient concentration of chlorine is present to continue providing protection against microbial contamination across the distribution network, residual chlorine levels are monitored.

Chlorine contact tanks allow the chlorine to react with and effectively kill or inactivate harmful microorganisms present in the water. Although the typical contact time is 20 min, the required contact time depends on several factors, such as the concentration of chlorine, water temperature, pH level, and the types and levels of contaminants in the water. Generally, higher chlorine concentrations, warmer temperatures, and lower pH levels contribute to faster disinfection rates and may require shorter contact times. In DWTPs, the contact time is regulated carefully to ensure adequate disinfection while minimizing the formation of DBPs (Rauen et al., 2012).

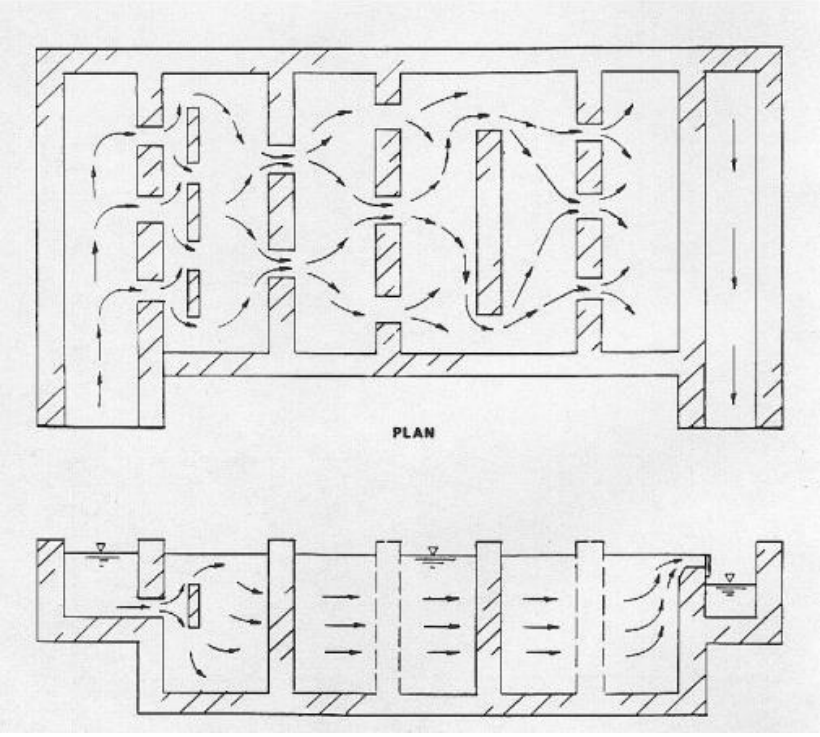

Figure 6. Chlorine contact tank from top and side view (Akgiray et al., 2003)

In Figure 6, the water flow through a chlorine contact tank is shown. To improve the hydraulic properties of a unit in terms of disinfection (to keep the T_{10}/T ratio high),

curtains are used. The purposes of the curtains are as follows: (1) to reduce stagnant areas called “dead volume” in the unit, (2) To prevent the water passing through the unit from leaving the unit in a much shorter time than T = V/Q by short-circuiting, possibly due to wind or density differences, (3) To ensure that the water flows in a “piston-flow” manner as much as possible and to prevent the water entering the unit after mixing with the one entering first. All these goals are interrelated and can be achieved if certain design principles are followed.

2.5 Economics of DWTPs

The economic aspects of drinking water and wastewater treatment plants are multifaceted and crucial for both public health and the overall well-being of communities. These aspects encompass various components, including the costs of sourcing, treating, and distributing water, as well as the economic benefits associated with access to clean and safe drinking water. Establishing a DWTP is a complex and resource-based process, necessitating careful planning and analysis. It is important to make reliable cost calculations and estimates in the water sector based on financial and economic analysis (Young & Loomis, 2014)

Economic and financial analysis, specifically by proposing strategic solutions for the services, can reveal the necessary information before the decisions are made at the stages of project definition and preparation with the contribution they make. These analyzes help to design projects that are appropriately scaled and cost-effective and serve to eliminate the costs that may arise due to delayed and non-rational investments in the middle. While the targeting of the demand at different service levels and the use of public subsidies constitute the key areas of the analyses; the reforms to be made in the price tariff and the improvement of public service financing with both economic and financial value estimates are very important for the project follow-up and evaluation processes (Turner, 2004).

The financial analyses should be conducted following the establishment of the project’s feasibility through economic analyses. Financial analyses typically focus on assessing whether the project can generate sufficient income to offset the financial

costs incurred during both the construction and operation of the facility (Squire et al., 1975).

In economic analysis, discount rates are used to convert benefits and income streams into currencies in the reference year, and therefore, real prices in economic analysis do not cover inflationary effects but consider individual price changes. In a comparable way, the marginal cost of untreated water considers not only the investment, operating, and maintenance costs, which are calculated as average incremental costs but also the opportunity/shadow costs of water. The opportunity cost of water means that the benefit is waived in the next best alternative to water. When viewed from the benefit side, financial benefits include measurable and non-measurable benefits related to alternative water sources eliminated by the project and the use of new and additional supply sources (Handbook for the Economic Analysis of Water Supply Projects, 1999).

Accurate estimates of both CAPEX and OPEX are essential for financial planning concerning the installation of a DWTP. These estimates provide an understanding of the CAPEX and OPEX associated with building and running the water treatment plant. Effective financial planning is needed for budgeting and securing funding for the project. Knowing the costs associated with the construction and operation of a water treatment plant enables efficient allocation of funds to ensure the successful completion and sustainable operation of the DWTP to be built. Moreover, cost estimates help decision-makers make informed choices regarding the treatment process. Cost data, especially OPEX data is essential for assessing the water treatment plant's long-term sustainability. The OPEX data helps ensure the plant can deliver reliable service for a prolonged amount of time (Echevarria et al., 2022).

Many variables are used in the analysis of the economic and financial elements of drinking water treatment infrastructures. For example, the water used in DWTPs and in many industries is classified according to the source of water, namely high-land surface water, low-land surface water, groundwater, brackish well water, and sea water. In addition, it shows different features according to the scale of the plant and the technology used. They are necessary to start purification, and this is also costly. Despite all this, strategies, and principles with basically the same approach are

recommended for the pre-treatment phase of DWTPs. There are two important points in the financial and economic analysis of the plants. These are cost estimates (pre-feasibility, feasibility, financing, hiring, construction, commissioning, staff training, business investment costs, material/feature list, discovery, and operating costs) and projected cash flow (preparation, construction, total) (Ćetković et al., 2022).

In accordance with the United Nations Environment Program Agenda 21, the acceptance of all costs of the drinking water treatment with all planning and development stages has been put forward as a prerequisite for the sustainable management of water as a scarce fragile resource. During planning, in addition, to benefit investment, environmental protection, and operating costs, opportunity costs reflecting the most valuable alternative use of water should be taken into account. Pricing mechanisms should reflect, as far as possible, the actual cost incurred by using water as an economic commodity and the paying skills that people must access these goods. (United Nations, 1992).

Water treatment plants generally bring the quality of untreated water to drinking water standards. The costs incurred related to the treatment process during the performance of this function vary depending on the quality and source of untreated water, as well as the availability of treatment sources. For example, the cost of reverse osmosis treatment of brackish water depends on the salinity ratio, peak demand, and local energy costs (Stevie and Clark, 1980). The CAPEX and OPEX of DWTPs are mainly examined in the following sections.

OPEX of a DWTP involves costs for personnel, energy, chemicals, and equipment maintenance (Albolafio et al., 2022). These OPEX can be substantial, and they must be funded to ensure water quality and reliability.

2.5.1 Capital Expenditures

CAPEX is essential for building, expanding, or upgrading DWTPs to ensure they meet the growing demand for clean and safe drinking water. Investing in DWTPs helps maintain and improve water quality and safety standards. Upgrading treatment technologies, adding new filtration systems, or enhancing disinfection processes

requires capital investment to ensure the water supplied to communities meets regulatory standards and is safe for consumption.

The CAPEX of a DWTP encompasses various components, each contributing to the overall investment necessary for the design and construction (Table 1). CAPEX is usually divided into two components direct and indirect costs (Hinomoto, 1977). Direct costs are those that are directly attributable to the construction and operation of the water treatment plant, while indirect costs are supporting expenses necessary for the overall project but may not have a direct correlation to physical construction activities.

Table 1. Main components of CAPEX of a DWTP (Duah & Syal, 2017)

Direct Costs	**Indirect Costs**
Land acquisition and preparation	Design and engineering fees
Labarotary Equipment procurement	Training and personnel expenses
Mechanical Equipment procurement	Utilities (start-up period)
Construction and installation costs	Testing and analysis fees
Piping (installed)	Contingency and reserves
Electrical (installed)	Financing costs
Buildings (including services)	Insurance premiums
Service Plants (installed)	Legal fees
Permitting and regulatory compliance fees	Environmental impact assessments
Start-up costs	Consultancy fees
	Transport and logistics
	Landscaping and site improvement expenses
	Administration and overhead costs

As presented in Table 1, direct costs mainly cover the expenses incurred for the preparation and construction of the treatment plant system until the system becomes operational. Therefore, it also covers the costs related to the construction of the whole system and its equipment during the investment stage. The largest items in the total direct cost of the treatment plant are usually the construction of and procurement of treatment units. After the designated area is prepared for the treatment plant, the production of reinforced concrete or steel tanks for the process units is completed.

Laboratory materials and mechanical devices are supplied. The infrastructure works of the plant are completed. The power line is drawn from the nearest and least expensive place and generators are installed for possible outages. According to the European Commission (2024), these items account for approximately 75-80% of the total costs during the construction phase of the project (Directive - 2020/2184 - EN - EUR-Lex, 2020). These components collectively represent a substantial portion of the total direct cost during the construction phase of a treatment plant. The estimate provided by the European Commission suggests that around 75-80% of the total costs can be attributed to these items, highlighting their significance in project budgeting and planning. However, in a drinking water system, there are various stationary (built) plants consisting of treatment units such as filter units, rapid mix tanks, slow mix tanks, etc, and clean water tank pipes. The installation cost accounts for approximately 30% of the equipment cost (Okta Virtania & Siregar, 2017).

Indirect costs encompass commissioning of the treatment plant and conducting workplace experiments preparation of end-of-business plant projects and operation-maintenance instructions for the treatment plant. Indirect CAPEX is the costs that are not related to the physical construction and installation of the DWTP necessary for the intake of water through the treatment process. These costs are typically incurred to support the development, operation, and long-term sustainability of the water treatment plant. The indirect CAPEX that may be too high, include administrative costs, design and engineering fees, contingency, investment expenditures (depreciation expenses), and interest expenses (Whittington & Hanemann, 2006). The investment expenses related to the installation also include depreciation and interest spent on making the facility ready for use. Depreciation is an essential element in this approach, especially for fixed expenses, which allows the creation of the necessary resources for replacing large parts and equipment in the system, such as pipes, with new ones (Hunter et al., 2011).

2.5.1.1 Direct Costs

Direct costs refer to expenses that can be directly attributed to a specific product, service, project, or activity. These costs are typically traceable and vary with the

level of production or output. They are essential for calculating the total cost of delivering services and are distinguished from indirect costs, which are not directly tied to a specific output or can't be easily traced.

2.5.1.1.1 Land Acquisition and Preparation

Firstly, within this expense item, there is the determination of the boundaries of the site where the DWTP building will be built according to the prepared project of the treatment plant. In addition, leveling the site after the demolition of the existing structure, if any, on the designated facility area and applying the building on the site in accordance with the project, projecting the DWTP, construction and operation of the facility with special and technical specifications and according to the proposed and approved project of the contractor firm, the lowest point at the intersection of the basic excavation pit area, of course, free excavation is added to this expense item after the lowest point at the intersection with the ground is considered a free excavation floor elevation. The design of the DWTP, and the free excavation of the basic excavation pit area boundary, the dimensions of which will be determined according to the proposed or approved project, are added to this expense item.

Secondly, the width, depth, and size of the basic excavation pit, the excavation of the foundation at each depth under the upper level of the foundation on each floor, the removal of the excavation material from the excavation pit, ensuring the safety of life and property in the excavation pit, the correction of the excavation pit floor and side surfaces, compaction of the excavation floor, filling the gaps left at the excavation site after the construction is completed have also been added to the cost.

Finally, this parameter also includes according to the project, the treatment plant building, landscaping and connections, other units, entrance gate, landscaping, septic tank, etc. construction of the retaining and flood wall treatment structure. Procurement or purchase of all kinds of construction materials necessary for construction in accordance with national or international standards; transportation from the given or purchased place to the workplace and loading and unloading expenses related to this transportation, basic supply base and building environment.

Evacuation with drain flex, making of rough and thin plaster and ceiling plasters on interior facades, making of ceramic coating suitable for this area on floors and walls that remove wetness, all kinds of experiments and laboratories, insurance and overhead expenses were completed in such a way that the construction was maintained and delivered according to the project.

In short, it is the price that includes the DWTP, the plant building, and other outbuildings where landscaping is carried out.

2.5.1.1.2 Laboratory Equipment Procurement

The provision of specified chemicals, analysis kits, consumables, and laboratory devices (together with TSE and EC certificates) in accordance with National or equivalent International Standards, Norms and Specifications and ISO-certified and to provide chemicals, analysis kits, consumables, and laboratory devices. In addition, after the construction, mechanical and electrical works of the administrative building and laboratory are completed; the treatment plant must be supplied before commissioning and starting workplace experiments. Transportation from the place where it was supplied or purchased to the workplace, placement in the laboratory in the administration building, making its calibrations operational, and having all devices ready with calibrations are expenses for this expenditure. Moreover, the completion of chemicals, analysis kits, consumables, installation of laboratory devices, and delivery of working conditions, including all kinds of labor, tool and equipment expenses and general expenses, are included in the price of laboratory equipment belonging to the DWTP. The list of laboratory equipment is provided in Appendix G.

2.5.1.1.3 Mechanical Equipment Procurement

This expense parameter includes; pre-treatment units, aeration equipment, coagulation (rapid mixing) equipment, flocculation equipment, clarifier/sedimentation equipment, pressure filters, sludge disposal systems, heating, cooling, ventilation, plumbing, fire protection and safety equipment, compressor,

blower, cranes or monorail (necessary for the transportation and installation of equipment), supply and installation of pipes of the diameter and type to be considered appropriate in the treatment plant building expenses.

Also fallowing expenses included; from the cable coming from the transformer panel, the panel, the material inside the panel and the cables of the parts fed from the panel, from the cable of the main panel of the package treatment plant, the material inside the panel, the electrical installation of all parts fed from the panel, the main control panel to be controlled manually and automatically, the ultrasonic or capacitive type level measuring device for measuring the level of tanks and warehouses inside the DWTP, the raw water inlet of the plant, the purified suitable for water outlet flow rate, flow measurement system with AC measurement operation, suitable diameter for pipe diameter and self-flanged, muddy and turbulent type magnetic flow meter that can measure water flow measurement system, turbidity measurement system capable of measuring the plant value will be placed on the raw water and purified water line in the DWTP, pH measurement system capable of measuring the pH of the plant inlet and purified water outlet line. Moreover, there will be a chlorine measurement system capable of measuring the amount of chlorine balance in the water at the entrance and exit of the facility, a Programmable logic controller (PLC), and Supervisory Control and Data Acquisition (SCADA) software that can work fully automatically, including in-plant valves, and have inputs and outputs that can be operated locally and from the main control room, a computer for each line where we can monitor the system mimic diagram from the monitor. It includes the implementation of photocell-controlled and gradually illuminable environmental and road lighting, operation, protection, and grounding of the foundation in accordance with the new regulation.

2.5.1.1.4 Construction and Installation Costs

The construction and installation costs of DWTPs can vary significantly depending on several factors such as the plant's capacity, technology used, location, labor costs, materials, regulatory requirements, and site-specific conditions. Smaller plants usually employ conventional treatment processes such as sedimentation, filtration,

and disinfection. Large-size plants often require extensive infrastructure, advanced treatment processes, and significant engineering and construction efforts to meet the demands of densely populated urban areas or regions with high water consumption. It is important to note that these cost estimates are rough approximations and can vary based on project-specific factors.

2.5.1.1.5 Piping (installed)

One significant aspect of the CAPEX includes the costs associated with pipes used in the distribution system of treated water and pipes used to ensure the flow of water between the treatment units. The material of the pipe used is one of the main reasons why this expense item is wavy. Common materials for water distribution pipes include PVC (polyvinyl chloride), HDPE (high-density polyethylene), ductile iron, and concrete. Each material has its own cost per unit length and associated installation costs. In addition, the diameter and length of the pipe used are another factor that affects expenses. The diameter and length of the pipes required for the distribution system depend on factors such as the population served, the distance to travel, and the required flow rate. Larger-diameter pipes typically cost more per unit length than smaller ones.

2.5.1.1.6 Electrical (installed)

CAPEX for the energy supply of a treatment plant involves various expenses related to providing power to the facility. This includes the cost of purchasing and installing power generation equipment such as generators, solar panels, or wind turbines. The choice of equipment depends on factors like availability of fuel, environmental impact, and reliability requirements. It covers the cost of electrical wiring, transformers, and distribution panels needed to distribute power throughout the treatment plant site. It also includes backup power systems like batteries or uninterruptible power supplies (UPS) to ensure continuous operation during power outages. Big spaced airline poles, inner-city alternative current lines painted iron sleepers and consoles for utility poles PVC sheathed cable circle section filled

copper, all kinds of transportation, loading and unloading, casualty and insurance expenses of insurance and similar cables and electric poles are included in this expense item.

2.5.1.1.7 Buildings

The operating buildings in DWTPs refer to the structures used to manage, and monitor the daily operations of the plant. These buildings are designed to meet the administrative needs of the facility and provide a working environment for the operating personnel. Administration offices, engineering and maintenance offices, meeting rooms, storage areas, and security rooms are some of these structures.

2.5.1.1.8 Service Facilities

In a DWTP, service facilities are essential installations that support the operation, maintenance, and administration of the plant. These facilities are critical for ensuring the efficient and effective treatment of drinking water. Laboratory, storage areas, administration building, security building, etc. the buildings are located within this expense item.

2.5.1.1.9 Permitting and Regulatory Compliance Fees

Permit application fees are one-time fees paid to regulatory agencies when applying for permits to construct, modify, or operate a DWTP. The fees can vary based on the type of permit being sought and the regulatory authority overseeing the permitting process. Annual operating fees are fees for regulatory agencies. They often charge annual fees for the continued operation of DWTPs. These fees may cover activities such as water quality monitoring, inspections, and administrative costs associated with regulatory oversight. Laboratory testing fees are required to conduct regular water quality testing to ensure compliance with regulatory standards. Laboratories may charge fees for sample analysis, including testing for parameters such as turbidity, pH, disinfection byproducts, and heavy metals.

2.5.1.1.10 Start-up Costs

Start-up costs refer to the initial investments required for the commissioning of the plant before it operates at full capacity. These costs refer to the expenses that may arise during the installation of the plant. Laboratory installation expenses are the costs associated with setting up a water quality-testing laboratory, including the purchase of equipment, instruments, reagents, and consumables necessary for monitoring and analyzing water samples. These are feasibility studies and engineering design costs related to conducting feasibility studies, environmental impact assessments and engineering design studies to determine the viability of the project and develop construction plans.

2.5.1.2 Indirect Costs

Indirect capital expenses associated with the commissioning of a DWTP and conducting workplace experiments include various expenses that are not directly related to the construction or operation of the plants but are necessary to ensure its successful implementation and operation.

2.5.1.2.1 Design and Engineering Fees

Design and engineering fees refer to fees paid for the design, planning and engineering work of a plant prior to construction. These costs consist of expenses such as project design, engineering calculations, and creation of drawings.

These fees are essential for creating detailed plans and specifications that guide the construction and implementation of the DWTP. Engineering design and detailed drawings are included in this expense item. They are fees for engineering firms to develop detailed design plans, drawings, and specifications for DWTP infrastructure, including treatment processes, pipelines, structures, and equipment layouts. This includes civil, structural, mechanical, electrical, and process engineering design studies.

2.5.1.2.2 Training and Personnel Expenses

In the context of a DWTP, training and personnel expenses cover the costs associated with training personnel, providing professional development opportunities, and ensuring that personnel are equipped with the necessary knowledge and skills to effectively operate and maintain the facility. Many parameters such as operator training, certification programs, and occupational health and safety training are included in this expense.

2.5.1.2.3 Utilities during the Start-up Period)

The phrase "DWTP start-up period" refers to the period before the plant reaches full operation after the installation of the plant. This period includes several activities, including system tests. During the startup period of a DWTP, utility expenses refer to the costs associated with essential services required to initiate and commission the plant. Safety and security systems are included in this expense item. Utility expenses may also include costs related to the installation and operation of safety and security systems such as fire alarms, security cameras, access control systems, and perimeter fences to protect the DWTP during the initial phase.

2.5.1.2.4 Testing and Analysis Fees

During the start-up period of a DWTP, testing and analysis fees refer to the costs associated with conducting various tests, analyses, and assessments to ensure the proper functioning and compliance of the facility. These expenses are crucial for verifying the effectiveness of treatment processes, assessing water quality, and meeting regulatory requirements.

2.5.1.2.5 Contingency and Reserves

In the context of a DWTP, contingency and reserves refer to funds set aside to cover unexpected expenses, unforeseen challenges, or changes in project scope during the

start-up period and beyond. These contingency and reserve funds are essential for mitigating risks, ensuring financial stability, and maintaining project timelines.

2.5.1.2.6 Financing Costs

Financing costs in the context of a DWTP refer to the expenses associated with securing and servicing the funds needed for the construction, operation, and maintenance of the facility. These costs include various financial charges and fees incurred during the borrowing or financing process. Interest payments, loan origination fees, loan closing costs, etc. many cost items are included in this expense.

2.5.1.2.7 Insurance Premiums

Insurance premiums in the context of a DWTP refer to the payments made by the facility to insurance companies in exchange for coverage against various risks and liabilities associated with its operations. These premiums are essential for protecting the DWTP against potential losses, damages, or legal claims.

2.5.1.2.8 Legal Fees

Legal fees in the context of a DWTP refer to the expenses incurred for legal services and counsel during various stages of the project, including planning, development, construction, operation, and compliance. Legal services play a crucial role in ensuring regulatory compliance, managing risks, resolving disputes, and protecting the interests of DWTP stakeholders. For example, contract drafting and negotiation is one of the legal fees. Expenses for drafting, reviewing, and negotiating contracts with vendors, suppliers, contractors, consultants, and other parties involved in the DWTP project. Attorneys help ensure that contractual terms are fair, enforceable, and aligned with the interests of the DWTP owner or operator.

2.5.1.2.9 Environmental impact assessments

Environmental impact assessments (EIAs) are crucial for evaluating the potential environmental consequences of constructing and operating a DWTP. The costs associated with EIAs for DWTPs can vary depending on factors such as the scale of the project, the complexity of the environmental considerations, and regulatory requirements.

2.5.1.2.10 Consultancy fees

Indirect CAPEX consultancy fees for a DWTP refer to the expenses incurred for professional consulting services that support the planning, design, construction, and commissioning of the facility but are not directly tied to physical assets or equipment. These consultancy fees cover a wide range of services provided by external consultants or firms to facilitate the successful implementation of the DWTP project.

2.5.1.2.11 Transport and Logistics

Transport and logistics indirect CAPEX for a DWTP encompasses the expenses associated with the transportation and logistical aspects of acquiring materials, equipment, and supplies necessary for the construction, operation, and maintenance of the facility. These costs cover various activities related to the movement and handling of goods throughout the project lifecycle (Themido et al., 2000).

2.5.1.2.12 Landscaping and site improvement expenses

Landscaping and site improvement expenses as indirect CAPEX for a DWTP encompass the costs associated with enhancing the aesthetic appeal, functionality, and environmental sustainability of the facility site. These expenses contribute to creating a safe, attractive, and environmentally friendly environment surrounding the DWTP. Field preparation is a parameter included in this cost item. Costs associated with site cleaning, grading, and excavation to prepare the land for construction

activities and landscape improvements. Site preparation expenses may include excavation, soil stabilization, drainage improvements, and erosion control measures to ensure a stable foundation for landscape features. Landscape design is another parameter. Fees for hiring landscape architects or design consultants to develop landscape plans, site layouts and planting designs for the DWTP site. Landscape architects take into account factors such as site topography, soil conditions, climate, water availability, and aesthetic preferences when designing landscape features (Ilbank, 2013).

2.5.1.2.13 Administration and overhead costs

Administration and overhead costs for DWTPs project encompass various indirect expenses associated with the project's management, supervision, and support functions. These costs are essential for ensuring the smooth operation and successful completion of the project. Professional services, safety, and indirect labor costs such as associated with administrative support staff, clerical personnel, and other indirect labor required to support project activities such as filing, data entry, correspondence, and administrative tasks are included in this cost (Ilbank, 2013).

2.5.2 Operational Expenditure

OPEX is an abbreviation of the term "Operational Expenditure". OPEX refers to the costs spent on the daily or yearly operation of a business and the maintenance of its activities. These expenses include routine expenses required for the enterprise to carry out basic activities. The parameters are summarized in Table 2.

Calculating OPEX in DWTPs involves considering the ongoing OPEX for maintaining and running the plant. Calculation the energy consumption of the treatment plant, including electricity and fuel costs. This involves estimating the energy requirements for pumps, motors, blowers, mixers, and other equipment used in the treatment process. Also, determination of the costs of chemicals used in the treatment process. This includes coagulants, flocculants, disinfectants (such as chlorine or ozone), pH adjusters, and any other chemicals necessary for water

treatment. Estimation of the labor costs associated with operating the treatment plant. This includes salaries for operators, maintenance staff, supervisors, and any other personnel involved in the day-to-day operation and maintenance of the plant.

Table 2. Main parameters for the DWTPs' OPEX

Components
Energy Consumption
Chemical Cost
Consumables and Supplies
Personnel Expenditures
Maintenance-Repair Expenses
Laboratory Testing
Waste Disposal

2.5.2.1 Energy Consumption

Energy consumption in DWTPs can vary significantly depending on factors such as the size of the plant, the treatment processes used, the quality of the source water, and operational practices. However, some common factors that contribute to energy consumption in DWTPs are pumping, treatment processes, aeration, sludge treatment, and distribution. Reducing energy consumption in DWTPs is important for both environmental and economic reasons. Strategies for energy efficiency may include optimizing pump operations, implementing more energy-efficient treatment technologies, utilizing renewable energy sources such as solar or wind power, and improving overall plant design and operation to minimize energy losses. Additionally, energy management systems and monitoring tools can help identify areas where energy-saving opportunities exist and track progress toward energy efficiency goals.

2.5.2.2 Chemical Cost

Chemical expenditures in DWTPs are a significant part of the OPEX. These expenditures primarily include the cost of various chemicals used in the treatment processes to ensure the quality and safety of drinking water. Coagulants like alum or ferric chloride (to destabilize particles in the water, allowing them to clump together and form larger particles), disinfectants (chlorine, chloramines, or chlorine dioxide are commonly used to disinfect water and kill or inactivate harmful microorganisms such as bacteria, viruses, and protozoa), stabilizers and antiscalants (These chemicals are used to prevent scaling and fouling of equipment and pipes by controlling the precipitation of minerals such as calcium carbonate or magnesium hydroxide), activated carbon (activated carbon is often used for taste and odor control, as well as the removal of organic compounds and certain chemicals through adsorption), and pH adjusting chemicals (Chemicals like lime or soda ash are used to adjust the pH of the water to optimize the effectiveness of other treatment processes and ensure compliance with regulatory standards) (Ilbank, 2013).

2.5.2.3 Consumables and Supplies

The OPEX for consumables and supplies in a DWTP encompasses various expenses related to the purchase and replenishment of materials necessary for the plant's operation and maintenance. Filter media such as sand, activated carbon, anthracite, or multimedia filters are used in filtration processes to remove suspended solids, particles, and contaminants from the water. These filter media need periodic replacement or backwashing to maintain their effectiveness. If the DWTP utilizes membrane filtration technologies such as RO or UF, expenses for membrane modules and replacement membranes are part of the consumables budget. Membrane replacement intervals vary depending on factors such as water quality, fouling rates, and operating conditions. Cleaning agents, detergents, sanitizers, and disinfectants are used for cleaning and sanitation purposes in the DWTP, laboratory, and other facilities. Other miscellaneous supplies and consumables, such as lubricants,

sealants, gaskets, fittings, and maintenance tools used for routine maintenance and repairs in the treatment plant.

2.5.2.4 Personnel Expenditures

OPEX for personnel expenditures in DWTPs includes the costs associated with hiring, training, and retaining staff to operate and maintain the facility. Salary includes the primary component of personnel expenditures and includes the salaries and wages paid to employees working at the DWTP. This includes plant operators, maintenance technicians, laboratory staff, administrative personnel, and management. Staffing Level is the number of personnel required to operate and maintain the DWTP affects personnel expenditures. Staffing levels are determined based on factors such as the size and complexity of the treatment plant, regulatory requirements, and operational needs. Uniforms and Safety Equipment are included in this cost. Providing uniforms, personal protective equipment (PPE), and safety gear to employees to ensure their safety and compliance with regulatory standards.

2.5.2.5 Maintenance-Repair Expenses

Maintenance and repair expenses in DWTPs encompass the costs associated with the upkeep, repair, and replacement of the plant's infrastructure, equipment, and facilities. These expenditures are essential for ensuring the reliable operation of the treatment plant and maintaining water quality standards. Routine maintenance, equipment replacement, infrastructure upgrades (investments in upgrading or modernizing the plant's infrastructure to improve efficiency, reliability, and compliance with regulatory requirements. This could involve replacing aging pipes, upgrading filtration systems, or installing new control systems). Efficient management of maintenance and repair expenses is essential for optimizing the OPEX of DWTPs while ensuring the reliability and safety of the water supply.

2.5.2.6 Laboratory Testing

The OPEX of laboratory testing in a DWTP involves various costs associated with conducting water quality testing and analysis to ensure the safety and compliance of the treated water. Data management is included in OPEX, which associated with managing and storing laboratory data, including software licenses, database management systems, and IT infrastructure for data storage and retrieval. In some cases, DWTPs may need to contract external laboratories to conduct specialized tests or analyses that cannot be performed in-house. Costs for external testing services may include fees for sample analysis, expedited processing, or rush orders. In order to provide accurate and reliable test results, the costs associated with calibrating and maintaining laboratory equipment are included in OPEX. This includes the costs of calibration standards, reference materials, maintenance kits, and service contracts for equipment maintenance and repair.

2.5.2.7 Waste Disposal

Waste disposal costs in the OPEX of a DWTP typically involve expenses associated with managing and disposing of waste generated during the treatment process. Sludge disposal is one significant waste product generated in the treatment process. It consists of solid materials separated from the water during treatment. Sludge disposal costs may include fees for transporting sludge to a landfill, incinerator, or composting facility. Alternatively, some DWTPs have on-site plants for dewatering and processing sludge before disposal. Chemical waste is the treatment process that may involve the use of various chemicals for disinfection, coagulation, and pH adjustment. Disposal of chemical waste may involve proper handling, storage, and transport to an appropriate disposal facility. Residuals from the treatment process like byproducts generated during the treatment process, such as filter media, spent cartridges, or spent resins, may require proper disposal. Costs associated with the disposal of these residuals depend on their composition and volume. Hazardous waste management includes additional costs that may be incurred for compliance

with hazardous waste regulations. This may include proper labeling, storage, handling, and disposal of hazardous waste materials.

CHAPTER 3

LITERATURE REVIEW

The need for potable and clean water has increased, driving the construction and growth of water treatment plants around the world. Planning and implementing such facilities naturally require a thorough grasp of the related expenses. In this situation, sound financial analysis of water treatment plants becomes essential for making wise decisions and allocating resources in a sustainable manner. The purpose of this review of the literature is to investigate and summarize the body of knowledge existing in the literature regarding the cost estimation of DWTPs. Through an exploration of case studies, this review aims to offer insights into the major aspects that influence the financial environment around water treatment projects and how decision-makers can utilize these estimates.

Cost functions are mathematical functions used to model the costs that a business or a project spends to perform a certain activity. These functions are usually used to analyze the costs of the activities of enterprises, such as production, distribution, or service delivery. Cost functions may vary depending on factors such as the amount of production, inputs, and other variables. DWTPs often try to optimize these functions to minimize costs. Cost functions are essential for DWTPs for several reasons. Cost functions help in optimizing the operation of the treatment plant. By understanding the cost associated with different processes, equipment, and inputs (such as chemicals, energy, and labor), plant operators can make decisions to minimize costs while meeting regulatory requirements and ensuring water quality standards. Also, cost functions play a crucial role in budgeting and long-term planning for the DWTP. By estimating the costs associated with maintenance, upgrades, and expansions, plant managers can develop accurate budgets and make informed decisions about investments in infrastructure and technology. Moreover, Cost functions help in evaluating the performance of the DWTP. By comparing actual costs with predicted costs based on the cost functions, managers can assess the efficiency of the plant's operation and identify areas where improvements can be

made. In brief cost functions are indispensable tools for managing the operation, maintenance, and planning of DWTPs, ensuring efficient use of resources while maintaining water quality and compliance with regulations.

There is no cost index showing the price increases in DWTPs in Turkey (Topçu, 2004) studied for the purpose of developing an index that reflects the conditions of DWTPs in Turkey and showed the cost increases in DWTPs. In line with this study, cost analyses were carried out by examining the exact calculations of the Taşoluk DWTP, which has a capacity of 50,000 m^3/day, and is being built by ISKI in Istanbul. As a result of this examination, the costs are classified into 8 groups as construction items, transportation, electricity (1) items, electricity (2) items, mechanical items, equipment items, engineering services items, and various items. The ratios of cost components in each group affecting the total cost, unit price differences between years, price increase percentages, and weighted price increase percentages have been determined and the principles for deconstructing the index have been established. With the help of this study, weighted price increase percentages and cost indexes will be calculated using the unit prices of the items used during the construction of DWTPs for the following years.

Arief et al. (2010) applied economic modeling to predict the most economic treatment among three wastewater treatment plants containing conventional activated sludge without denitrification (CAS), conventional activated sludge with pre-denitrification (CAS-N), and membrane bioreactor (MBR). They used CapdetWorks software to calculate the cost of treatment plants. The wastewater flow considered was 30,000 m^3/day. Results demonstrated that the cost of the MBR plant is higher than that for the CAS and CAS-N by about 57%, and 42% respectively. Furthermore, the price per cubic meter of influent flow of the CAS plant is 0.2 \$/m^3. Dissimilarity, the costs of the CAS-N and MBR plants are 0.27 \$/m^3 and 0.43 \$/m^3, respectively (Arif et al., 2020).

According to Sharma (2010), the CAPEX and OPEX of DWTPs are essential for the planning and design of treatment plants. These costs are used to evaluate the financial and economic benefits of the project. Additionally, these costs are essential for the evaluation and comparison of the cost and benefits of different alternatives to select

the most feasible alternative. Sharma (2010) indicated the evaluation of CAPEX and OPEX for water treatment plants that involves regression analysis and the use of some cost functions. The characteristics chosen as independent factors are plant capacity, surface area, and volume. CAPEX and OPEX were considered as the dependent variables. The cost projections produced by these cost functions are simply rough projections and do not accurately reflect the project's total cost. The actual construction costs of the projects strongly rely on the site's circumstances, the weather, the level of supplier and bidder competition, and the general local and national economic climate. Because of this, accurate cost estimates for development, operation, and maintenance must be created specifically for each project. The project's full cost estimate should be developed using design specifications and cost projections based on quantities of supplies, machinery, and personnel (Sharma, 2010).

Recently, Ozgun et al. (2021) published a study that is similar to this thesis with one difference. The study evaluated the cost of the wastewater treatment plants in İstanbul and developed some cost functions for the estimation of CAPEX and OPEX. The study presents the OPEX and CAPEX for the 16 preliminary and tertiary wastewater treatment plants (WWTPs) located in Istanbul. The tertiary WWTPs with relatively modest capacity had the highest unit CAPEX, whereas those with medium and large capacity had slightly lower prices. The capacity, start-up year, and treatment levels of the WWTPs are summarized in Table 3. For preliminary and tertiary WWTPs, the total CAPEX per unit volume of treated wastewater was determined to be 0.013 ± 0.004 €/m^3 and 0.054 ± 0.009 €/m^3, respectively. For the preliminary and tertiary treatments, the total OPEX per unit volume was determined to be 0.011 ± 0.007 €/m^3 and 0.077 ± 0.021 €/m^3, respectively.

Table 3. Detailed information about WWTPs (Ozgun et al., 2021)

WWTP Code	Year of start-up	Treatment level	Capacity (m^3/day)	Capacity Level
SP1	2008	Preliminary	46,000	Small
SP2	1992	Preliminary	77,760	
ST1	2016	Tertiary	36,500	
ST2	2016	Tertiary	52,000	
ST3	2017	Tertiary	70,000	
MP1	2003	Preliminary	354,000	Medium
MP2	2009	Preliminary	570,000	
MT1	2016	Tertiary	132,500	
MT2	2000-2009	Tertiary	200,000	
MT3	1998-2009	Tertiary	250,000	
MT4	2012	Tertiary	400,000	
LP1	1997	Preliminary	625,000	Large
LP2	2004	Preliminary	640,000	
LP3	2003	Preliminary	833,000	
LP4	1988	Preliminary	864,000	
LT1	2010-2018	Tertiary	600,000	

Following the above-mentioned main classification, preliminary and tertiary treatment plants were divided into three categories based on their treatment capacity: small (>100,000 m^3/day), medium (100,000-400,000 m^3/day), and big (>400,000 m^3/day). Each WWTP was assigned a code based on its treatment level: “P” for preliminary treatment and “T” for tertiary treatment. Furthermore, the treatment capacity categories were denoted by a code (S for small, M for medium, and L for large) in Table 3. With a plant lifespan of 30 years and a real interest rate of 3%, investment expenditures for the analyzed WWTPs were projected out to 2018. For the year 2018, information on the energy and OPEX of WWTPs was supplied. To calculate the 2018 value of CAPEX, the following equation (1) was employed. A particular quantity of money is represented by "F" as its future value, "P" as its present value, i as its interest rate per period, and "n" as its period.

$$F = P\,x\,(1+i)^n \qquad \text{Eq (1)}$$

The cost analysis in this study was split into two stages: the CAPEX and the OPEX cost analysis. Construction and equipment costs are the two classifications under

CAPEX. The installation costs for the treatment and sludge-handling units, as well as other components, are included in the CAPEX. The cost of the equipment comprises the instruments for the sludge handling and treatment units as well as the cost of cogeneration, energy, and automation. A 20% share of consulting fees and other unidentified costs were included in the CAPEX study. Energy, labor, chemicals, sludge disposal, maintenance, and repair charges are among the five cost components that make up OPEX. Chemical costs cover the price of the chemical reagents used for sludge conditioning and wastewater treatment. In conclusion, the preliminary and tertiary WWTPs were determined to have total CAPEX per unit volume of treated wastewater of 0.013 ± 0.004 €/m^3 and 0.054 ± 0.009 €/m^3, respectively. For the preliminary and tertiary treatments, the total OPEX per unit volume was determined to be 0.0110.007 €/m^3 and 0.0770.021 €/m^3, respectively.

According to the study of Ozgün et al. (2021), the amount of treatment has a considerable impact on the overall cost of WWTPs. The equipment cost was the most significant cost factor in the investment in preliminary WWTPs, while construction cost accounted for the largest percentage of the investment in tertiary WWTPs. The most significant cost item for the OPEX cited as energy expenses for both preliminary and tertiary WWTPs.

Friedler & Pisanty (2006) studied the economic impact of design flow and treatment level on municipal WWTPs in Israel. They examined 55 WWTPs to evaluate their CAPEX and to develop cost models. For each treatment level, statistically significant ($p<0.01$) were developed, suggesting a potential weakening of economies of scale with increasing treatment levels. The study found that the proportional cost of civil engineering decreased with increasing design flow (negative correlation, $p<0.05$), while the proportional cost of electromechanical equipment increased with ($p<0.05$). There was no significant correlation between the proportional cost of electricity and control and design flow. It was discovered that OPEX values were 20–70% more sensitive to treatment level than building costs. It was discovered that while the share of building costs reduced concurrently, the share of operation expenses as a percentage of total annual expenditures increased with both design flow and

treatment level. The final section of the research discusses how the findings could affect policy and, in turn, the efficiency of treatment plants.

Jacimaria et al. (2020) study focused on the energy expenses of large capacity DWTPs and examined this expense with the energy-carbon nexus approach. With a population of more than 2 million, the DWTP considered in the study is situated in one of the southwestern United States' urban areas with the greatest rate of population growth. The Colorado River is the city's main water supply source. The chosen DWTP is used to treat one Mm^3 of water daily and is supplied with water. The managers of the factory specified that the site be kept secret when they gave the information necessary to verify the plant design. It was believed that the solar PV system's study would involve a Nevada-based facility (direct solar insolation level of 7.1 kWh m^2 day^{-1} was assumed). This study's objective was to apply a water-energy-carbon nexus approach for a DWTP by (a) calculating the energy consumption of the water treatment processes, (b) using PV as an energy source for the treatment plant based on economic considerations, and (c) quantifying the net reduction in carbon emissions because of PV development. Pre-ozonation (19.5 Wh m^{-3}), coagulation (1.3 Wh m^{-3}), flocculation (1.22 Wh m^3), filtering (0.32 Wh m^{-3}), chlorine disinfection (32.9 Wh m^{-3}), and residue management operations all required different amounts of energy (0.091Wh m^3). The operating energy needed for water treatment, including water distribution pumps, was approximately 65.5 MWh day-^{1} (57.7 Wh m^3), but the operational energy usage for the DWTP as a whole was roughly 577 MWh day^{-1} (508 Wh m^{-3}). The biggest energy user was the pumping process (Jacimaria et al., 2020).

Xie et al. (2022) did a study with the goal of renewability assessment of water cost for water purification in wastewater treatment plants in China. Wastewater treatment is crucial for recycling water resources and enhancing water quality in areas with severe water constraints and pollution. A case study of a typical wastewater treatment plant in China using a layered hybrid method that combines process analysis and system input-output analysis reveals the renewability of the wastewater treatment system as represented in the cost of water for water treatment. The scenario demonstrates the excellent renewability of the wastewater treatment plant. Based on

a normalized indicator of water investment in treated water, the industrial freshwater usage per cubic meter of treated wastewater is computed at 0.0069 m^3. Tap water and electrical inputs, which together account for 46.4% and 23% of the total industrial water consumption of the wastewater treatment system, are the main contributors, with the building phase contributing a minimal 19% of the total. The adoption of the most thorough input inventory and the layered hybrid method, which can effectively include both on-site and off-site water use, can be attributed to the fact that the water cost for water treatment by the case wastewater treatment plant is clearly higher than previous findings. The outcome offers a distinctive viewpoint for evaluating the renewability of wastewater treatment plants and serves as a guide for water conservation (Xie et al., 2022).

CHAPTER 4

METHODOLOGY

The methodology used in this thesis study is presented in this chapter.

4.1 Study Approach

The fundamental approach applied involves collecting DWTPs' CAPEX and OPEX data from the Illerbank and various other sources, categorizing the data based on plant treatment capacities, conducting separate assessments for CAPEX and OPEX for each category, and ultimately deriving CAPEX and OPEX functions for each category. Figure 7 presents the key steps involved in the cost analysis of DWTPs during the study. In the following sections, a detailed exploration of the key stages undertaken in this research is provided.

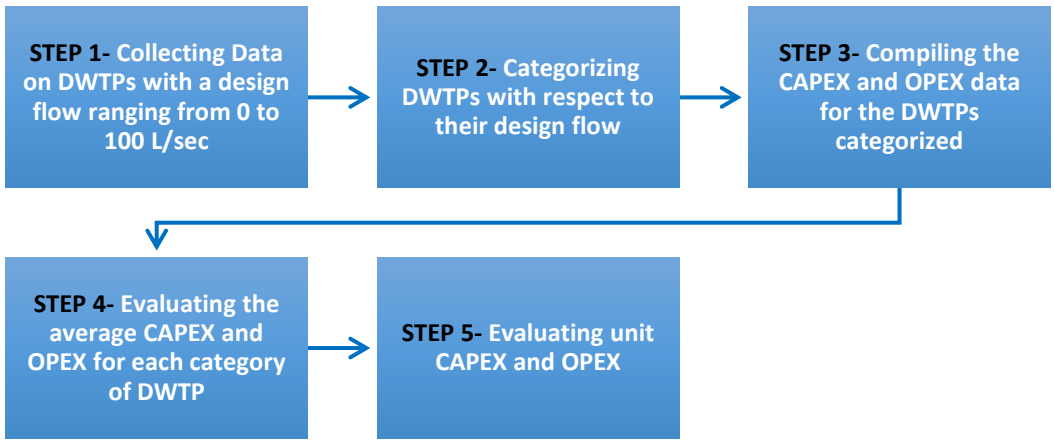

Figure 7. The steps involved in the cost analysis of DWTPs

STEP 1 – Collecting Data

The data on the DWTP with a design flow ranging from 0 to 100 L/sec were compiled. The data compiled covers municipalities with a population ranging from

about 3,000 (7 L/sec) to 50,000 (100 L/sec). When collecting this data, consideration was given to capacities of 100 L/s and below, the similarity of raw water quality and the utilization of surface water as a source. Appendix presents the raw water quality for 4 of the DWTPs covered in the present study. While data was being compiled from the plants that Ilbank has built or assisted in the operation, it was taken by mail with the form of an information paper or by visiting to the plant. With the information of other plants, it was learned by mail with the permission of the managers or operators of the institutions. The major source was the Ilbank as it is an institution responsible for developing infrastructure projects for municipalities in Turkey, carrying out construction implementation works, to providing consultancy and technical services.

A total of 42 DWTPs were examined in the study, and the data for these plants were compiled. CAPEX and OPEX data were collected through a multi-source approach, including direct interviews with DWTP managers and reviewing design project documents.

The abbreviations S and L in the tables correspond to the terms “small” and “large capacity DWTPs”, respectively.

Table 4 and Table 5 present information on the design flow, construction year, and processes applied for the small capacity and large capacity DWTPs, respectively. Due to confidentiality considerations, DWTP names are not provided; instead, the plants are numbered. As presented, the treatment processes applied in these DWTPs are almost the same. They all treat water by coagulation and flocculation followed by sedimentation, filtration and disinfection.

STEP 2- Categorizing DWTPs

The DWTPs have been divided into two groups based on their design flows: small (< 25 L/s) and large (≥ 25 L/s) DWTPs. As shown in The abbreviations S and L in the tables correspond to the terms “small” and “large capacity DWTPs”, respectively.

Table 4 and Table 5, collected CAPEX data for 25 small capacity DWTPs and 17 large capacity DWTPs compiled. In addition, the OPEX data for 2022 is compiled in Table 6 and Table 7

STEP 3- Compiling CAPEX and OPEX Data

Data on the CAPEX and OPEX for the DWTPs were compiled and then updated for the 2022 cost figures. As the original cost figures are for the year of establishment, the cost values were updated to the 2022 figures.

CAPEX and OPEX data collected are for the DWTPs with capacities ranging from 0 to 100 L/sec. For the CAPEX calculations the codes of DWTPs, the year they were built and started operating, their capacities, the TL values of their prices in the year they were operated, the Euro equivalents (calculated by dividing the exchange rate in that year published by the Central Bank of the Republic of Turkey), and processes applied are provided The abbreviations S and L in the tables correspond to the terms "small" and "large capacity DWTPs", respectively.

Table 4 and Table 5, for small and large capacity DWTPs, respectively. When the Table 6 and Table 7 was prepared for OPEX, the prices of personnel, electricity, chemicals, maintenance and repair expenses in Turkey in 2022 were determined, and the price for 2022 was multiplied by the amount of materials used. The abbreviations S and L in the tables correspond to the terms "small" and "large capacity DWTPs", respectively.

Table 4. CAPEX of small capacity DWTPs

Number	DWTP Code/ Year of establishment	Capacity (L/sec)	CAPEX (TL)	CAPEX (€)	Treatment Process
1	S1 / 2020	7	1,557,750.00	193,991.28	A+C+F+S+FT+D
2	S2/ 2012	7	298,400.00	129,739.13	A+ST+F+S+FT+D

Number	DWTP Code/ Year of establishment	Capacity (L/sec)	CAPEX (TL)	CAPEX (€)	Treatment Process
3	S3 / 2020	10	1,239,000.00	154,296.39	A+C+F+S+FT+D
4	S4 / 2011	10	606,719.79	261,517.15	A+C+F+S+FT+D
5	S5 / 2012	10	457,630.00	198,969.57	A+ST+F+S+FT+D
6	S6 / 2010	10	387,820.00	194,884.42	A+C+F+S+FT+D
7	S7 / 2010	10	351,000.00	176,381.91	A+C+F+S+FT+D
8	S8 / 2020	11	2,043,000.00	254,420.92	A+C+F+S+FT+D
9	S9 / 2018	12	1,060,000.00	187,279.15	A+C+F+S+FT+D
10	S10 / 2017	12	783,000.00	190,048.54	A+C+F+S+FT+D
11	S11 / 2011	12	479,606.00	206,726.72	A+C+F+S+FT+D
12	S12 / 2010	12	310,500.00	156,030.15	A+ST+F+S+FT+D
13	S13 / 2017	14	942,500.00	228,762.14	A+C+F+S+FT+D
14	S14 / 2018	15	1,080,900.00	190,971.73	A+ST+F+S+FT+D
15	S15 / 2011	15	400,000.00	172,413.79	A+C+F+S+FT+D
16	S16 / 2015	18	954,500.00	316,059.60	A+C+F+S+FT+D
17	S17 / 2011	18	740,587.27	319,218.65	A+C+F+S+FT+D
18	S18 / 2013	18	767,016.00	303,168.38	A+C+F+S+FT+D
19	S19 / 2020	19	3,362,500.00	418,742.22	A+C+F+S+FT+D
20	S20 / 2013	20	817,448.00	323,101.98	A+ST+F+S+FT+D
21	S21 / 2010	21	810,000.00	407,035.18	A+C+F+S+FT+D
22	S22 / 2020	22	3,780,558.23	470,804.26	A+C+F+S+FT+D
23	S23 / 2021	22	5,167,000.00	493,505.25	A+C+F+S+FT+D
24	S24 / 2021	23	4,985,770.00	476,195.80	A+ST+F+S+FT+D
25	S25 / 2009	25	1,232,000.00	573,023.26	A+C+F+S+FT+D

(A: Aeration, C: Coagulation, ST: Static Mixer, F: Flocculation, S: Sedimentation, FT: Filtration, D: Disinfection)

Table 5. CAPEX of large capacity DWTPs

Number	DWTP Code/ Year of establishment	Capacity (L/Sec)	CAPEX (TL)	CAPEX (€)	Treatment Process
1	L1 / 2015	30	708,000.00	234,437.09	A+C+F+S+FT+D
2	L2 / 2010	30	546,294.84	274,520.02	A+ST+F+S+FT+D
3	L3 / 2018	33	1,248,000.00	220,494.70	A+C+F+S+FT+D
4	L4 / 2016	33	780,110.75	233,566.09	A+C+F+S+FT+D
5	L5 / 2018	36	976,000.00	172,438.16	A+ST+F+S+FT+D
6	L6 / 2014	40	941,000.00	323,367.70	A+C+F+S+FT+D

Number	DWTP Code/ Year of establishment	Capacity (L/Sec)	CAPEX (TL)	CAPEX (€)	Treatment Process
7	L7 / 2015	42	907,000.00	300,331.13	A+C+F+S+FT+D
8	L8 / 2018	49	1,807,000.00	319,257.95	A+ST+F+S+FT+D
9	L9 / 2020	50	3,967,545.00	494,090.29	A+C+F+S+FT+D
10	L10 / 2011	50	935,759.90	403,344.78	A+C+F+S+FT+D
11	L11 / 2017	52	1,510,000.00	366,504.85	A+C+F+S+FT+D
12	L12 / 2013	54	1,106,250.00	437,252.96	A+ST+F+S+FT+D
13	L13 / 2020	70	6,902,000.00	859,526.77	A+C+F+S+FT+D
14	L14 / 2022	70	12,748,000.00	781,127.45	A+ST+F+S+FT+D
15	L15 / 2020	100	8,814,031.00	1,097,637.73	A+C+F+S+FT+D
16	L16 / 2015	100	3,828,000.00	1,267,549.67	A+C+F+S+FT+D
17	L17 / 2021	100	13,233,022.29	1,263,898.98	A+C+F+S+FT+D

(A: Aeration, C: Coagulation, ST: Static Mixer, F: Flocculation, S: Sedimentation, FT: Filtration, D: Disinfection)

Table 6. OPEX of small capacity DWTPs

Number	DWTP Code/ Year of establishment	Capacity (L/sec)	OPEX (€)	Treatment Process
1	S1 / 2020	7	58,702.43	A+C+F+S+FT+D
2	S2/ 2012	7	57,252.54	A+ST+F+S+FT+D
3	S3 / 2020	10	57,891.17	A+C+F+S+FT+D
4	S4 / 2011	10	61,793.60	A+C+F+S+FT+D
5	S5 / 2012	10	62,843.97	A+ST+F+S+FT+D
6	S6 / 2010	10	66,346.93	A+C+F+S+FT+D
7	S7 / 2010	10	65,578.91	A+C+F+S+FT+D
8	S8 / 2020	11	67,390.73	A+C+F+S+FT+D
9	S9 / 2018	12	68,231.46	A+C+F+S+FT+D
10	S10 / 2017	12	70,196.46	A+C+F+S+FT+D
11	S11 / 2011	12	72,282.77	A+C+F+S+FT+D
12	S12 / 2010	12	71,854.64	A+ST+F+S+FT+D
13	S13 / 2017	14	76,449.88	A+C+F+S+FT+D
14	S14 / 2018	15	78,261.73	A+ST+F+S+FT+D
15	S15 / 2011	15	77,010.18	A+C+F+S+FT+D
16	S16 / 2015	18	79,837.08	A+C+F+S+FT+D
17	S17 / 2011	18	77,623.99	A+C+F+S+FT+D
18	S18 / 2013	18	79,022.13	A+C+F+S+FT+D
19	S19 / 2020	19	83,929.86	A+C+F+S+FT+D
20	S20 / 2013	20	87,333.51	A+ST+F+S+FT+D
21	S21 / 2010	21	98,413.07	A+C+F+S+FT+D
22	S22 / 2020	22	102,030.86	A+C+F+S+FT+D

Number	DWTP Code/ Year of establishment	Capacity (L/sec)	OPEX (€)	Treatment Process
23	S23 / 2021	22	103,779.39	A+C+F+S+FT+D
24	S24 / 2021	23	106,510.47	A+ST+F+S+FT+D
25	S25 / 2009	25	115,592.66	A+C+F+S+FT+D

(A: Aeration, C: Coagulation, ST: Static Mixer, F: Flocculation, S: Sedimentation, FT: Filtration, D: Disinfection)

Table 7. OPEX of large capacity DWTPs

Number	DWTP Code/ Year of establishment	Capacity (L/sec)	OPEX (€)	Treatment Process
1	L1 / 2015	30	100,031.53	A+C+F+S+FT+D
2	L2 / 2010	30	104,386.30	A+ST+F+S+FT+D
3	L3 / 2018	33	106,463.83	A+C+F+S+FT+D
4	L4 / 2016	33	106,604.45	A+C+F+S+FT+D
5	L5 / 2018	36	113,517.21	A+ST+F+S+FT+D
6	L6 / 2014	40	121,631.71	A+C+F+S+FT+D
7	L7 / 2015	42	128,140.62	A+C+F+S+FT+D
8	L8 / 2018	49	139,560.53	A+ST+F+S+FT+D
9	L9 / 2020	50	153,709.87	A+C+F+S+FT+D
10	L10 / 2011	50	149,684.42	A+C+F+S+FT+D
11	L11 / 2017	52	161,592.61	A+C+F+S+FT+D
12	L12 / 2013	54	169,552.84	A+ST+F+S+FT+D
13	L13 / 2020	70	198,737.26	A+C+F+S+FT+D
14	L14 / 2022	70	197,722.09	A+ST+F+S+FT+D
15	L15 / 2020	100	243,882.62	A+C+F+S+FT+D
16	L16 / 2015	100	244,304.41	A+C+F+S+FT+D
17	L17 / 2021	100	250,774.43	A+C+F+S+FT+D

(A: Aeration, C: Coagulation, ST: Static Mixer, F: Flocculation, S: Sedimentation, FT: Filtration, D: Disinfection)

4.2 Evaluation of CAPEX

During the CAPEX calculations for the construction of DWTP, various factors that differ from treatment plant to treatment plant were not taken into account. This was mainly due to the variability in parameters such as the slope of the area or the distance to the stream in different geographical regions in Turkey. Comparable DWTPs were chosen according to their respective areas in order to facilitate a more accurate comparison. This made it possible to compare expenses for excavation and

landscaping. Additionally, the requirement for various equipment options was removed because there were no particular pollutants among the raw water parameters across different plants. As a result of these considerations, there was no requirement for extra generators or electrical line withdrawals for energy. The primary focus was on the plant capacity as the key variable. Consequently, the raw water intake structure, the transmission lines between the water intake structure and the plant, as well as network costs for the water supply were not factored into the CAPEX calculations.

The main CAPEX items considered in the present study are outlined in Table 8. Building and treatment system costs are included in the scope of CAPEX that could be incurred during installation and maintenance. As can be seen from a comparison of the items listed in this table with those in Table 1, the items considered in the present study are grouped under more general headings. This organization is based on the data collected for the purpose of the study.

Table 8. Components in the CAPEX calculations of DWTPs

<table>
<tr><th colspan="3">Components</th></tr>
<tr><th colspan="2">Direct Costs</th><th rowspan="2">Indirect Costs</th></tr>
<tr><th>Construction Cost</th><th>Equipment Cost</th></tr>
<tr><td>Treatment Plant Building, Landscaping, and Excavation Cost</td><td>Treatment Plant Mechanical-Instrument and Electrical Cost</td><td rowspan="3">Commissioning of the Treatment Plant and Conducting Workplace Experiments</td></tr>
<tr><td>Treatment Plant Laboratory Materials Cost</td><td>Treatment Plant Generator</td></tr>
<tr><td rowspan="2">Treatment Plant Energy Supply Cost</td><td rowspan="2">Treatment Plant Power Transformer</td></tr>
<tr><td>Preparation of End-Of-Business Plant Projects and Operation-Maintenance Instructions for Treatment Plant</td></tr>
</table>

The CAPEX data from different past years was adjusted to present-day values following a 2-step methodology given below:

1. Converting each cost figure in TL to € based on Euro/TL exchange rates are taken from the Central Bank of the Republic of Turkey (Table 9). The DWTP data in this study begins with the oldest value recorded in 2005.
2. Calculating the inflation-adjusted costs for the year 2022 using the average EU inflation rate for each year from the European Central Bank (Table 10).

Table 9. Exchange rates published by the Central Bank of the Republic of Turkey (TCMB - Gösterge Niteliğindeki Merkez Bankası Kurları, n.d.)

Year	Exchange Rate	Year	Exchange Rate
2005	1.67	2014	2.91
2006	1.80	2015	3.02
2007	1.78	2016	3.34
2008	1.90	2017	4.12
2009	2.15	2018	5.66
2010	1.99	2019	6.35
2011	2.32	2020	8.03
2012	2.30	2021	10.47
2013	2.53	2022	18.50

A sample calculation is given below:

The CAPEX of the “S1” DWTP = 1,789,112 TL in 2020.

The corresponding cost is €; 1,789,112 (TL) / 8. 03 (TL/€) = 222,803 €

According to the European Central Bank (ECB), the interest rate that banks pay when they borrow money from the ECB overnight is known as the marginal lending facility rate. They must offer collateral, such as securities, as an assurance that the money

will be repaid when they do this. The interest rates sourced from the ECB/EUROSYSTEM are summarized in Table 10.

Table 10 The interest rate of the ECB

Year	Euro Region Interest Rate (%)	Year	Euro Region Interest Rate (%)
2005	3.25	2014	0.35
2006	4.00	2015	0.30
2007	4.88	2016	0.25
2008	4.21	2017	0.25
2009	2.38	2018	0.25
2010	1.00	2019	0.25
2011	2.00	2020	0.25
2012	1.50	2021	0.25
2013	0.88	2022	0.75

If we continue the same example, the CAPEX of the S1 is 1,789,112.00 TL in 2020

$$\text{Inflation} - \text{adjusted cost at } 2021 = \text{Cost at } 2020 \text{ x } (1 + \text{i for } 2020)$$

i for 2020 = 0.25 %

F_{2021}= 222,803 € x (1+0.0025)

Cost adjusted to 2021 = 223,360 €.

This conversion was repeated to adjust the cost to 2022.

Cost adjusted to 2022 = 223,918 €

These CAPEX calculations were performed separately for 42 plants and the results were given in Appendix C and D.

4.3 Evaluation of OPEX

In Chapter 2.5.2, OPEX is explained in detail. Energy consumption, chemicals, personal expenditures, consumables supplies, laboratory testing, waste disposal, and maintenance costs are the main expenditures, which can be seen in Table 2.

When calculating OPEX for DWTPs, although the first five items listed in Table 2 (energy consumption, chemical cost, consumables and supplies, personnel expenditures, and maintenance-repair expenses) were considered, comsumables and supplies are considered in the chemical expenses. As the data for the other two items (laboratory testing and waste disposal) are not available, they were not taken into account. The choice of similar processes ensured that there was no fluctuation in energy consumption between plants, and similar pollutants also ensured that the consumption of chemicals in different DWTPs could be compared. The only major difference observed was in the choice of chemicals for coagulation or flocculation purposes; while some DWTPs use alum, others use ferric salts. It is important to note that this variation in chemical usage can impact the overall OPEX of the treatment plants. The key points that make the main difference in OPEX include the expansion of mechanical equipment as DWTPs capacities grow and the increase in personnel expenses due to operational challenges. It has been tried to ensure that the only big variable in OPEX calculations is the DWTP capacity.

To calculate OPEX for the year 2022, OPEX data from the various past years was collected from the operators of DWTPs and from field employees of the ILBANK. This included information such as unit chemical prices purchased by the plant operators, the number of personnel employed based on plant capacity, salary expenses, and unit prices for electricity usage, which were obtained from the plant operators, ILBANK regional directorate employees, and supplier companies. The

collected data was then multiplied by the 2022-unit costs obtained from these sources.

As an example, the chemical expenses account of a DWTP (S1) is shown in Table 11.

Table 11 Chemical OPEX for the DWTP (S1)

Chemical Name	**Amount (kg/year)**	**Unit Price (TL/kg)**	**Total (TL)**
PAC	89,790	5.00	448,950.00
NaOH	11,972	11.00	131,692.00
$FeCl_3$	2,952	5.00	14,760.00
PE (cationic)	121	50.00	6,050.00
AC	340	36.50	12,410.00
Cl	4,392	1.20	5,270.40
PE (anionic)	92	58.00	5,336.00
TOTAL Chemical Cost (TL/year)			**624,468.40**

As can be seen in Table 11, different chemicals are used during drinking water treatment processes. The annual amount of chemicals used is multiplied by the unit prices for the year 2022 and the total expenses for 1 year are found as TL.

Similar to the chemical expense calculation, electricity, personnel, maintenance and repairment are also made and the summation is given in the Table 12 for the plant "S1" below. Some important points were taken into account when calculating electricity costs. For example, some plants need to be transferred with pumps due to the elevation difference between the raw water intake point and the plant. At this time, the electricity used by the pumps was excluded from these calculations.

Another example is the case of pumps used during the transmission of treated water. In this case, it was not included in the electricity expenditures again.

Table 12 Total OPEX for the DWTP (S1)

DWTP Code	Unit	OPEX (TL/year)
S1	Electric	78,555.25
	Chemical	624,468.40
	Personnel	240,000.00
	Maintenance and Repairment	15,000.00
	Total OPEX	**958,023.65**
	Flow (L/sec)	7
	Unit Water Cost (TL/m³)	**4.34**

After calculating the total OPEX, it was converted to the € by dividing the TL /€ exchange rate (16.32) for 2022 that is shown below.

Total OPEX (€) = 958,023 (TL) / 16.32 (TL /€) = 58,702 €

To calculate OPEX for 1 m^3 water, total OPEX divided into the plant capacity.

Unit Water Cost (TL/m^3) =

958,023 (TL) / ((7 (L/sec) x 31,536 (year/m^3)) = 4.34 (TL/m³)

Unit Water Cost (€/m^3) = 4.34 (TL/m³) / 16.32 (TL /€) = 0.27 (€ /m³)

4.4 Evaluation of Total Cost

The evaluation of the total cost of a DWTP involves considering all the expenses associated with the design, construction, operation and maintenance of the plant. This comprehensive assessment is essential for ensuring that the treatment plant remains sustainable, cost-effective, and efficient in providing safe and clean drinking water to the community.

The total cost typically includes the two major components; CAPEX and OPEX. The other cost items are lifecycle costs and environmental and social costs. The study exclusively concentrated on CAPEX and OPEX without considering lifecycle costs or environmental and social costs.

When planning or budgeting for a DWTP project, it is important to understand the cost per unit of water treated. This information helps decision-makers compare different treatment options and estimate the overall project cost based on the desired capacity.

The total cost or combined cost per cubic meter of water processed was determined by aggregating the OPEX per m^3 and CAPEX per m^3, assuming a 35-year lifespan for a DWTP.

To this end, the CAPEX for each plant is divided by two factors:

1. Annual flow rate: The volume of water treated by the plant each year.
2. Lifetime of the DWTP (taken as 35 years): This spreads the CAPEX cost over the expected lifespan of the plant.
3. Unit Water CAPEX calculation: By performing this division, the CAPEX per unit volume of water treated is evaluated.

CHAPTER 5

RESULTS AND DISCUSSION

This chapter presents the results of the cost analysis performed throughout the thesis.

The CAPEX and OPEX figures gathered for 42 DWTPs in Turkey were grouped based on treatment capacity, ranging from 0 to 25 L/sec and 26 L/sec to 100 L/sec. These data sets were then used to develop cost functions for evaluating CAPEX, OPEX, and total costs for DWTPs in Turkey.

The cost data was then adjusted to 2022 and then utilized in the evaluation of CAPEX for small and large capacity DWTPs, as detailed in Appendices C and D respectively. The adjusted OPEX cost data used for the assessment of OPEX for small and large capacity DWTPs is presented in Appendices E and F, respectively.

5.1 CAPEX

Both linear and nonlinear models were tested to analyze the changes in CAPEX as a function of capacity. Comparisons were made separately for two distinct categories: direct CAPEX (encompassing construction and equipment expenses) and indirect CAPEX. It is anticipated that both direct and indirect costs will increase with the expansion of plant capacity. Evaluating the rise in CAPEX required an examination of the correlation coefficients (R^2) of the graphs to determine the degree of correlation and predictability in the cost escalation patterns across the different models.

5.1.1 CAPEX of the Small DWTPs

Figure 8 shows the variation in the equipment CAPEX for small capacity DWTPs as capacity increases. This visual representation provides insight into how the evolution of costs associated with equipment procurement in relation to the scale of the DWTP.

As depicted, equipment expenses range from 75,000 € to 325,000 € correlating with a capacity increase from 7 to 25 L/sec.

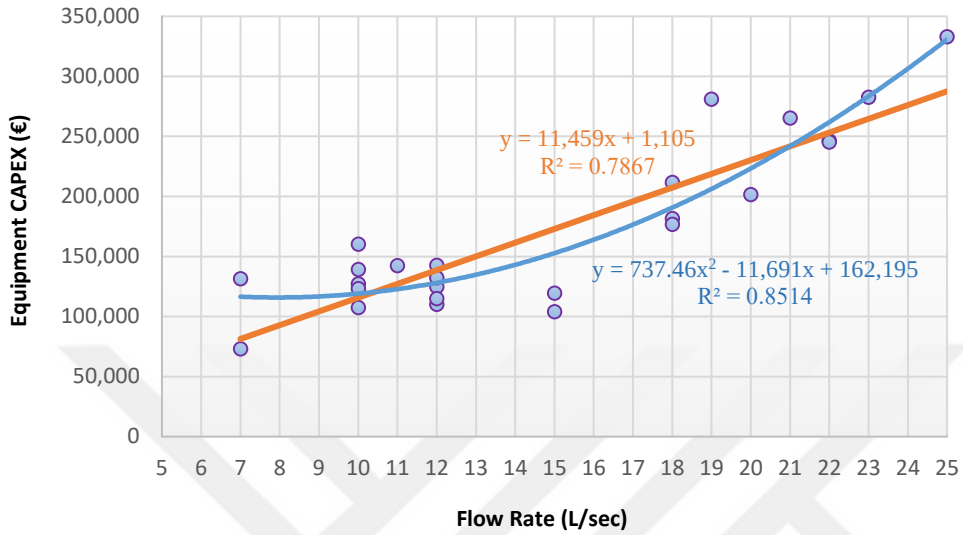

Figure 8. Equipment CAPEX of small capacity DWTPs

The trend in equipment CAPEX for small capacity DWTPs demonstrates a consistent increase, underlining a positive correlation with flow rate and CAPEX (Figure 8). As capacity increases, equipment CAPEX also increases in line with the economies of scale principle. The principle of economies of scale suggests that as the scale of production increases, the cost per unit of output decreases. To develop the best cost function, linear and polynomial increases were tested by comparing the correlation coefficient (R^2) of each model. The coefficient of determination indicates how well the model fits the data points. A higher R^2 value suggests a better fit. As seen, the quadratic model has an R^2 of 0.8514, which is higher than the linear model's R^2 of 0.7867. This suggests that the quadratic model provides a better fit to the data, indicating a non-linear relationship between equipment CAPEX and DWTP capacity. Therefore, based on the R^2 values, the quadratic model appears to be more suitable for representing the relationship between capacity and equipment expenses in small capacity DWTPs.

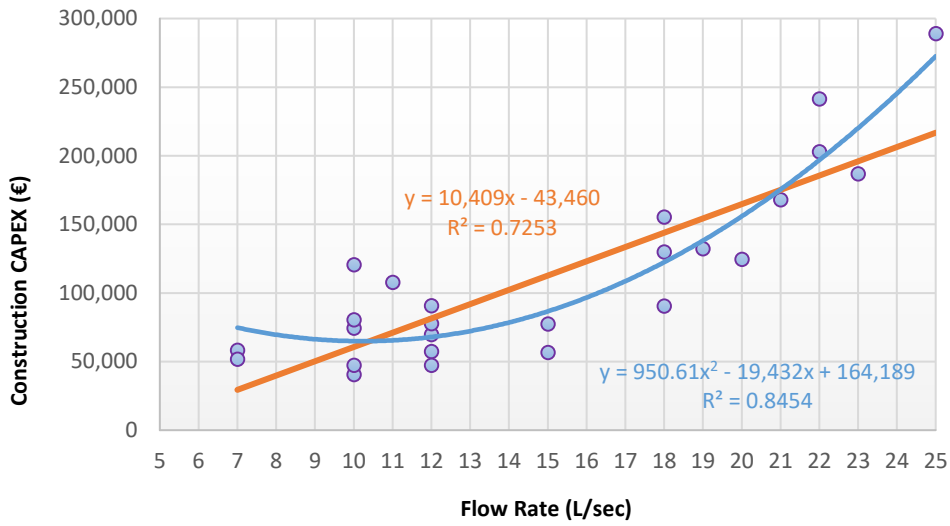

Figure 9. Construction CAPEX of small capacity DWTPs

As depicted in Figure 9, construction CAPEX ranges from 50,000 € to 275,000 € correlating with a capacity increase from 7 to 25 L/sec. Further analysis of the graph in Figure 9 revealed a clear trend: the construction expenses component of CAPEX exhibits a polynomial increase as capacity increases. This observation signifies that construction expenses escalate at a rate that surpasses the rate of capacity growth in smaller DWTPs. The polynomial increase means an increase in construction expenses faster than the rate of capacity increase in small capacity plants. Furthermore, when comparing the linear and polynomial models, the coefficient of determination (R^2) for the polynomial model was found to be higher (e.g., a quadratic model with R^2 of 0.8454) compared to the linear model (with lower R^2 value of 0.7253). This suggests that the polynomial model provides a better fit to the data, supporting the non-linear relationship between construction expenses and DWTP capacity in small capacity plants.

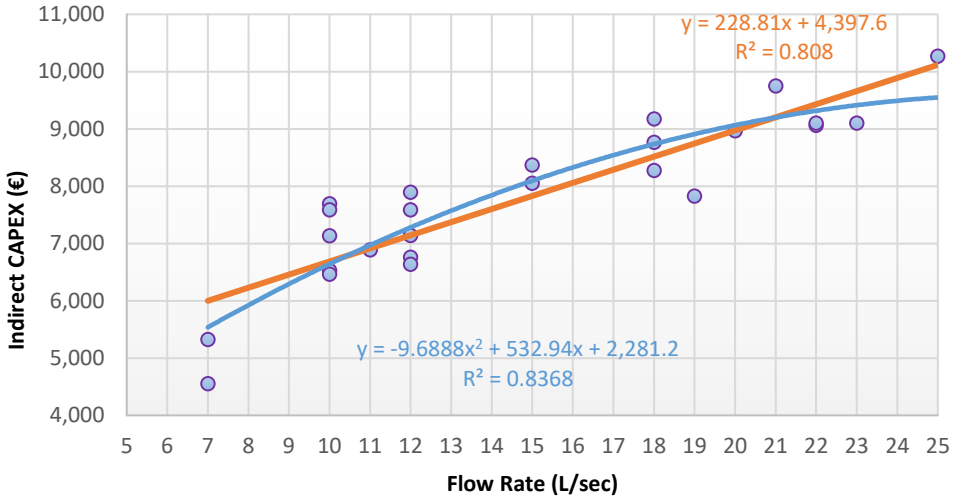

Figure 10. Indirect CAPEX of small capacity DWTPs

Figure 10 shows that the indirect CAPEX for small capacity DWTPs in Turkey is quite low, ranging from 4,500 to 10,200 €. Further, the data in Figure 10 illustrates the change in indirect CAPEX as the capacity of DWTP changes, showing a similar polynomial increase trend as observed in the direct CAPEX. Unlike direct CAPEX, the difference between linear and polynomial graphs is minimal for indirect costs. When this difference between polynomial and linear graphs is negligible, it implies that the data is not deviating significantly from linear patterns.

In such cases where the difference between the polynomial and linear models is minimal, it may suggest that a linear model is adequate for describing the relationship between the variables under analysis. This implies that the relationship between the capacity of the DWTPs and the corresponding indirect costs can be adequately explained by a linear model. While there is a polynomial increase in indirect CAPEX, the closeness of the linear and polynomial trends suggests that the linear model may suffice to capture the nuances in the relationship between capacity and indirect CAPEX in this context.

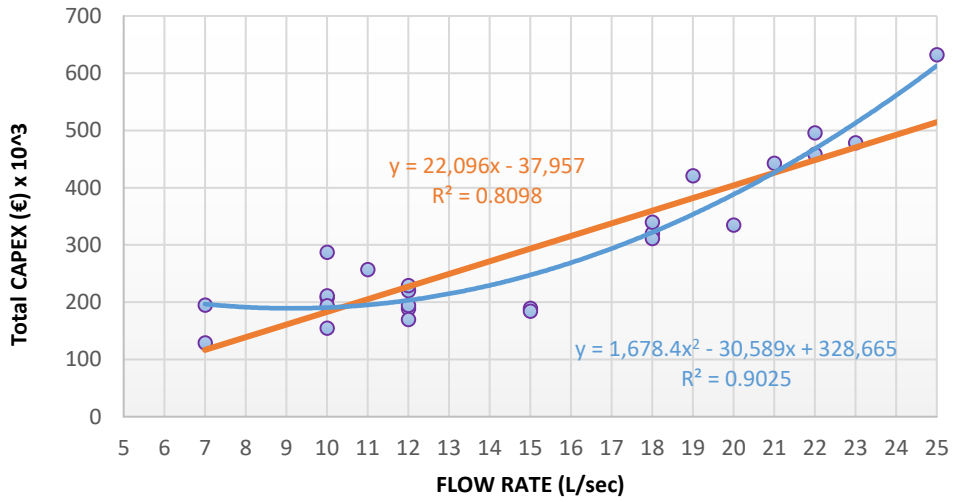

Figure 11. Total CAPEX of small capacity DWTPs

According to Figure 11 which shows the change in total CAPEX with capacity for small capacity DWTPs in Turkey, the total CAPEX ranges from about 100,000 to 630,000 €. When the change in CAPEX with the flow was further assessed, it was seen that the increase was not linear. It is evident that the R^2 value of the polynomial graph is significantly closer to "1" indicating a higher level of accuracy in depicting the relationship between variables. This suggests that the the total CAPEX appears to exhibit a polynomial increase as the capacity of the plant increases particularly in small-scale plants. In contrast, the data does not align with a linear correlation, as the behavior of the price increase displays a polynomial trend rather than a linear one. This observation reinforces the notion that in smaller plants, the relationship between plant capacity and pricing behaves in a non-linear manner, where the costs escalate in a polynomial fashion with increasing capacity.

Table 13 Direct and indirect costs percentages in total CAPEX of small DWTPs

DWTP Codes	Direct Costs		Indirect Costs (%)
	Construction Cost (%)	Equipment Cost (%)	
S1	29.87	67.40	2.73
S2	39.87	56.61	3.50
S3	26.07	69.33	4.60
S4	41.95	55.78	2.27
S5	35.71	61.18	3.10
S6	38.03	58.33	3.64
S7	24.30	71.79	3.91
S8	41.89	55.43	2.68
S9	31.59	64.83	3.59
S10	30.19	66.04	3.77
S11	39.85	56.67	3.48
S12	27.75	67.78	4.47
S13	39.48	57.63	2.89
S14	40.74	54.85	4.41
S15	30.71	64.92	4.37
S16	40.55	56.71	2.74
S17	45.62	51.95	2.43
S18	29.04	68.02	2.95
S19	31.38	66.77	1.86
S20	37.15	60.18	2.67
S21	37.90	59.90	2.20
S22	44.25	53.77	1.98
S23	48.66	49.51	1.84
S24	39.02	59.08	1.90
S25	45.70	52.68	1.62
Average	**36.69**	**60.29**	**3.02**

As can be expected, the direct and indirect costs will increase as the plant capacity increases. The pattern of increase in costs other than indirect expenses is in parallel with total CAPEX. Indirect expenses, on the other hand, are increasing at a slower rate than the plant growth rate. Also, Table 13 proves that the largest (approximately 60%) cost item of a plant is equipment cost, which is one of its direct costs. The

percentage of the indirect costs in total CAPEX of small capacity DWTPs was found to vary from 1.62 to 4.60 %, the average being 3.02%.

Table 14 illustrates the percentage distribution of total direct CAPEX among its sub-items. Direct costs item presented are construction expenses (treatment plant excavation, treatment plant energy supply, and laboratory materials) and equipment expenses (Mechanical, instrument and electrical, transformer for power and plant generator). In this table, which is made on the CAPEX of small plants, the minimum, maximum, and average values are given for the components of the CAPEX. When the data are examined, it is seen that almost 96% of the CAPEX is direct expenses, while indirect expenses can be negligible. It is observed that the highest expense item among direct expenses is the treatment plant mechanical-instrument and electrical expenses, and this expense component is more than 50% of the total direct expenses. This component varied between 46% and 67% in 25 small capacity DWTPs. Although the proportion of indirect expenses is very low, when examined with details of the components, it is seen that the commissioning of the treatment plant and conducting workplace expense is two times higher than component preparation of end-of-business plant projects and operation-maintenance instructions of the treatment plant expense. More detailed table in which the percentages of all plants are given is given in Appendix B.

Table 14 Minimum, maximum, and average percentages (% of total expenses) of the components of CAPEX of small capacity DWTPs

CAPEX	**Direct Costs**						**Indirect Costs**	
	Treatment Plant Building, Landscaping and Excavation	Treatment Plant Laboratory Materials	Treatment Plant Mechanical-Instrument and Electrical	Treatment Plant Power Transformer	Treatment Plant Generator	Experiments Treatment Plant Energy Supply	Preparation of End-Of-Business Plant Projects and Operation-Maintenance Instructions for the Treatment Plant	Commissioning of the Treatment Plant and Conducting Workplace
Max	43.15	13.12	65.64	3.28	9.67	2.99	2.79	6.21
Min	13.56	0.92	45.16	0.28	0.87	0.81	0.48	0.29
Average	27.76 ± 0.07	6.14 ± 0.03	55.65 ± 0.06	1.45 ± 0.01	3.72 ± 0.02	1.62 ± 0.01	1.12 ± 0.01	2.60 ± 0.02

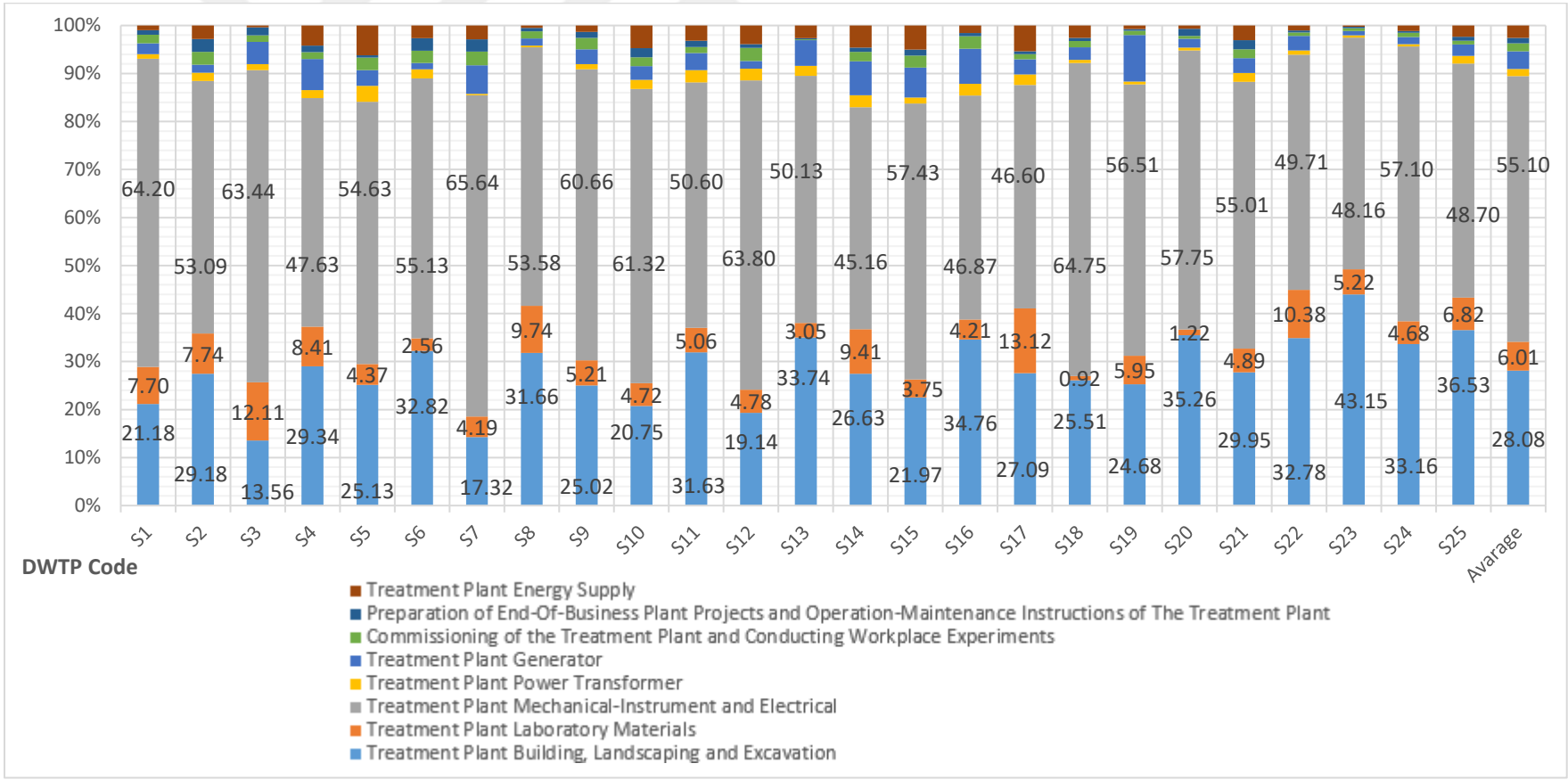

Figure 12. The cost distribution of the small capacity DWTPs with respect to components of total CAPEX

Each CAPEX component is examined separately, and the summary table is given in Table 14. Minimum, maximum, and average values within 25 plants are given in the table with percentages. Table 14 shows that treatment plant mechanical-instrument and electrical, which is by far the highest CAPEX, corresponds to 55% of total CAPEX at average values. The representation of the Table 14 is given in the bar chart in Figure 12. In Figure 12, each color shows a separate component of the CAPEX. The predominance of blue and gray colors in the graph shows how dominant the treatment plant building, landscaping, and excavation (blue) and treatment plant mechanical-instrument and electrical (grey) components are in the plant CAPEX. In addition, it can be easily concluded that the indirect expenses that give the sum of green and dark navy-blue colors are so few that they can be ignored.

According to the study conducted by Zessner et al. (2010) on WWTPs in Austria, nearly 70 % of the total cost is covered by land excavation, mechanical instruments, and electrical. This data is similar to the DWTPs. The only difference is in DWTPs the value is higher. Although there is more than one reason for this situation, the two most important reasons are the transmission network lines that are not covered by this thesis and the characteristics of the water treated by the plants (Zessner et al., 2010).

5.1.2 CAPEX of the Large DWTPs

As with small capacity DWTPs, when calculating CAPEX for large capacity DWTPs, the expenses of the parameters in the establishment year are found first and the total CAPEX is found for that year. Then, CAPEX for the year 2022 is calculated using equation (1). The results are divided into construction cost, equipment cost, and indirect cost.

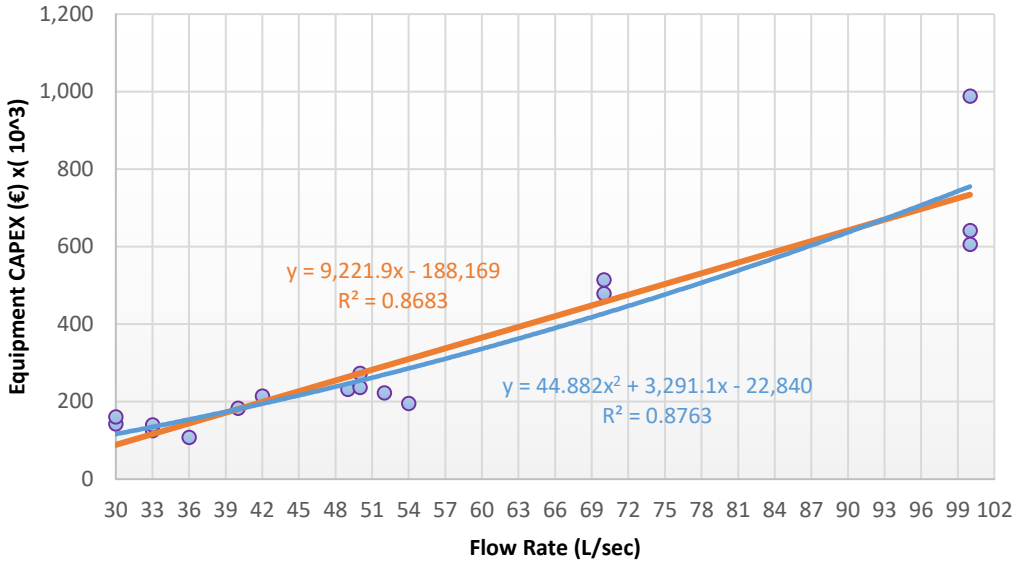

Figure 13 Equipment CAPEX of large capacity DWTPs

Although the polynomial increase is more stable since R^2 is closer to the 1, the values of R^2 are very close (0.8763 for the polynomial graph and 0.8683 for the linear graph), as can be seen in the graph in Figure 13. Since the difference between the polynomial and linear graphs is small, it could imply that there is not a significant deviation from linearity or polynomial in the data. This might suggest that a both linear model and polynomial model are sufficient to describe the relationship between the variables being analyzed.

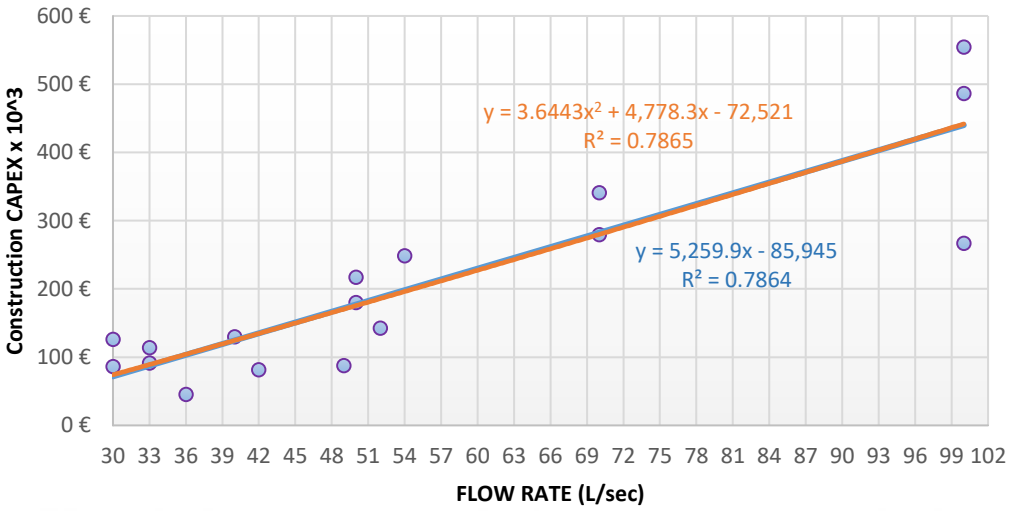

Figure 14 Construction CAPEX of large capacity DWTPs

In Figure 14, the y-axis shows the construction CAPEX in € x 10^3 and the x-axis shows the flow rate as L/sec. Construction CAPEX for capacities ranging from 30 to 100 L/sec changes between 45,505 to 554,532 €.

As can be seen from the graph in Figure 14, construction expenses (a component of CAPEX) in large capacity treatment plants do not show a difference as a polynomial increase or linear increase with increasing capacity, unlike equipment expenses. Interestingly, the correlation coefficient (R^2) for both the linear and polynomial models was nearly identical (0.7865 and 0.7864, respectively) which indicates both models have a similar degree of variability in the data. In other words, either a linear or polynomial relationships could be used to represent the data without a significant impact on the interpretation. Notably, this finding aligns with the economies of scale principle, where CAPEX may not increase proportionally with plant size or design flow. This is because certain fixed costs, such as land acquisition might not increase linearly with the scale of the plant. For instance, building a larger treatment plant might require more equipment and materials, but the increase in these costs might be less than proportional to the increase in capacity.

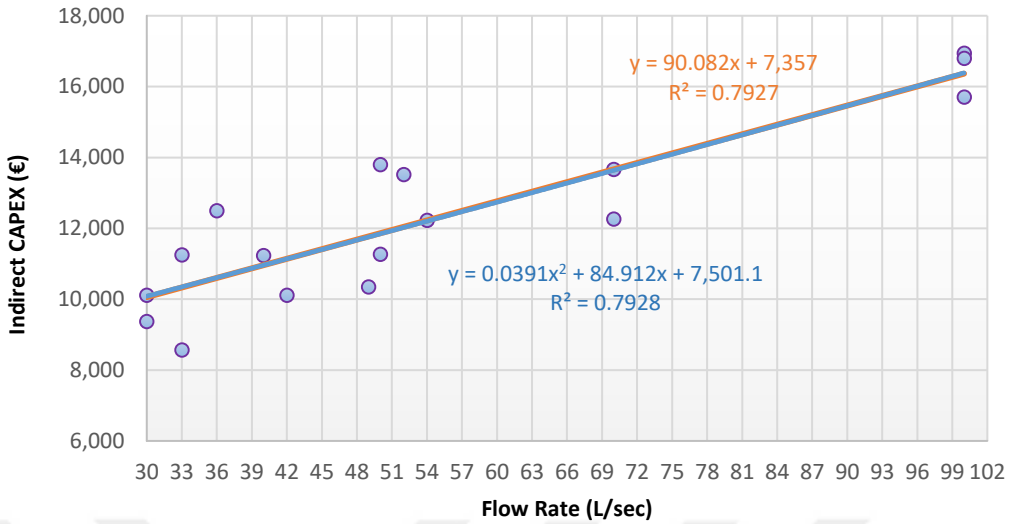

Figure 15 Indirect CAPEX of large capacity DWTPs

Figure 15 shows that the indirect CAPEX for large capacity DWTPs in Turkey ranges from 8,500 to 17,000 €. Although, as expected, there are much larger expenses than the indirect expenses of small capacity plants, it is clear that there is a small expense in the total CAPEX. Also, the data in Figure 15 shows the change in the indirect CAPEX as the capacity of the DWTP changes, and there does not seem to be a difference between a polynomial increase or a linear increase as observed in the direct CAPEX. The difference between linear and polynomial graphs is minimal in indirect CAPEX. This similarity between polynomial and linear graphs shows a linear pattern according to the shape of the graph.

If the direct and indirect expenses of small capacity plants are compared with those of large capacity plants, it is seen that the biggest difference is between the correlation coefficients of polynomial and linear models. In small capacity plants, the increase in expenses as capacity increases resembles the polynomial model, on the other hand, both linear or polynomial models have very close correlation coefficients in large capacity plants that show that both models are applicable.

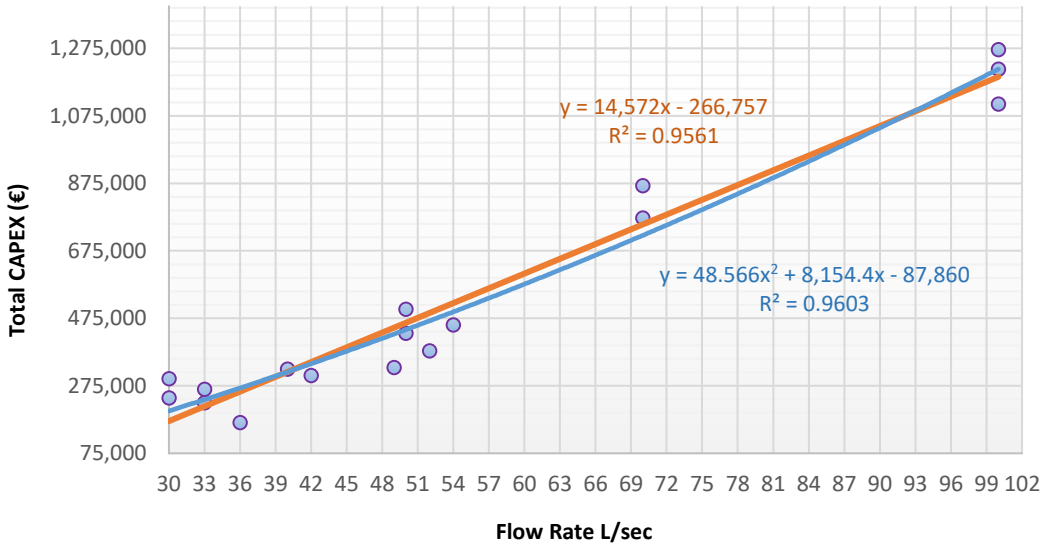

Figure 16 Total CAPEX of large capacity DWTPs

As seen in the graph in Figure 16, the R^2 value of both (polynomial graph and linear graph) graphs are close to "1" which means that both graphs are also valid.

From the large and small capacity capex graphs, it seems that as the capacities increase, the graphs give both more accurate and closer results. This shows that as the capacity of the plants grows, more stable results are obtained.

Table 15 Direct and indirect costs percentages in total CAPEX of large capacity DWTPs

DWTP Codes	Direct Costs		Indirect Costs (%)
	Construction Cost (%)	Equipment Cost (%)	
L1	36.02	59.75	4.24
L2	42.65	54.19	3.17
L3	40.62	55.56	3.82
L4	43.00	52.75	4.24
L5	27.42	65.05	7.53
L6	40.09	56.45	3.47
L7	26.68	70.01	3.31

DWTP Codes	Direct Costs		Indirect Costs (%)
	Construction Cost (%)	Equipment Cost (%)	
L8	26.56	70.30	3.14
L9	43.29	54.46	2.25
L10	41.78	55.01	3.21
L11	37.66	58.77	3.57
L12	54.53	42.79	2.68
L13	39.31	59.28	1.41
L14	36.20	62.03	1.77
L15	43.84	54.64	1.53
L16	45.72	52.90	1.38
L17	21.00	77.77	1.24
Average	38.02	58.92	3.06

As can be expected, the direct and indirect costs will increase as the plant capacity increases. The pattern of increase in direct and indirect costs is in parallel with total capex. Also, Table 15 proves to us that the largest (approximately 60%) cost item of a plant is equipment cost, which is one of its direct costs.

Direct and indirect costs are given in Table 14 with percentages. Direct costs which are construction expenses (treatment plant excavation, treatment plant energy supply, and laboratory materials)) and equipment expenses (Mechanical, instrument and electrical, transformer for power and plant generator) are given in detail. According to Ozgun et al. (2021), the results were similar in preliminary plants. In WWTPs, construction cost component is lower than the equipment cost for the preliminary treatment plants, however in the secondary treatment, construction cost is higher with a small difference.

The minimum, maximum, and average values for the CAPEX components of the large capacity DWTPs are given in Table 16. This table shows that the biggest CAPEX component is treatment plant mechanical-instrument and electrical expenses. A more detailed table for each plant is in Appendix B.

Table 16 Minimum, maximum, and average percentages (% of total expenses) of the components of CAPEX of large capacity DWTPs

CAPEX	**Direct Costs**						**Indirect Costs**	
	Treatment Plant Building, Landscaping and Excavation	Treatment Plant Laboratory Materials	Treatment Plant Mechanical-Instrument and Electrical	Treatment Plant Power Transformer	Treatment Plant Generator	Treatment Plant Energy Supply	Preparation of End-Of-Business Plant Projects and Operation-Maintenance Instructions of The Treatment Plant	Commissioning of the Treatment Plant and Conducting Workplace Experiments
Max	42.46	7.84	77.04	3.79	7.06	6.45	2.29	7.45
Min	14.03	1.36	38.88	0.26	0.28	0.76	0.08	1.87
Average	29.02 ± 0.07	4.46 ± 0.02	54.78 ± 0.08	1.35 ± 0.01	2.79 ± 0.02	2.02 ± 0.01	1.04 ± 0.01	4.54 ± 0.02

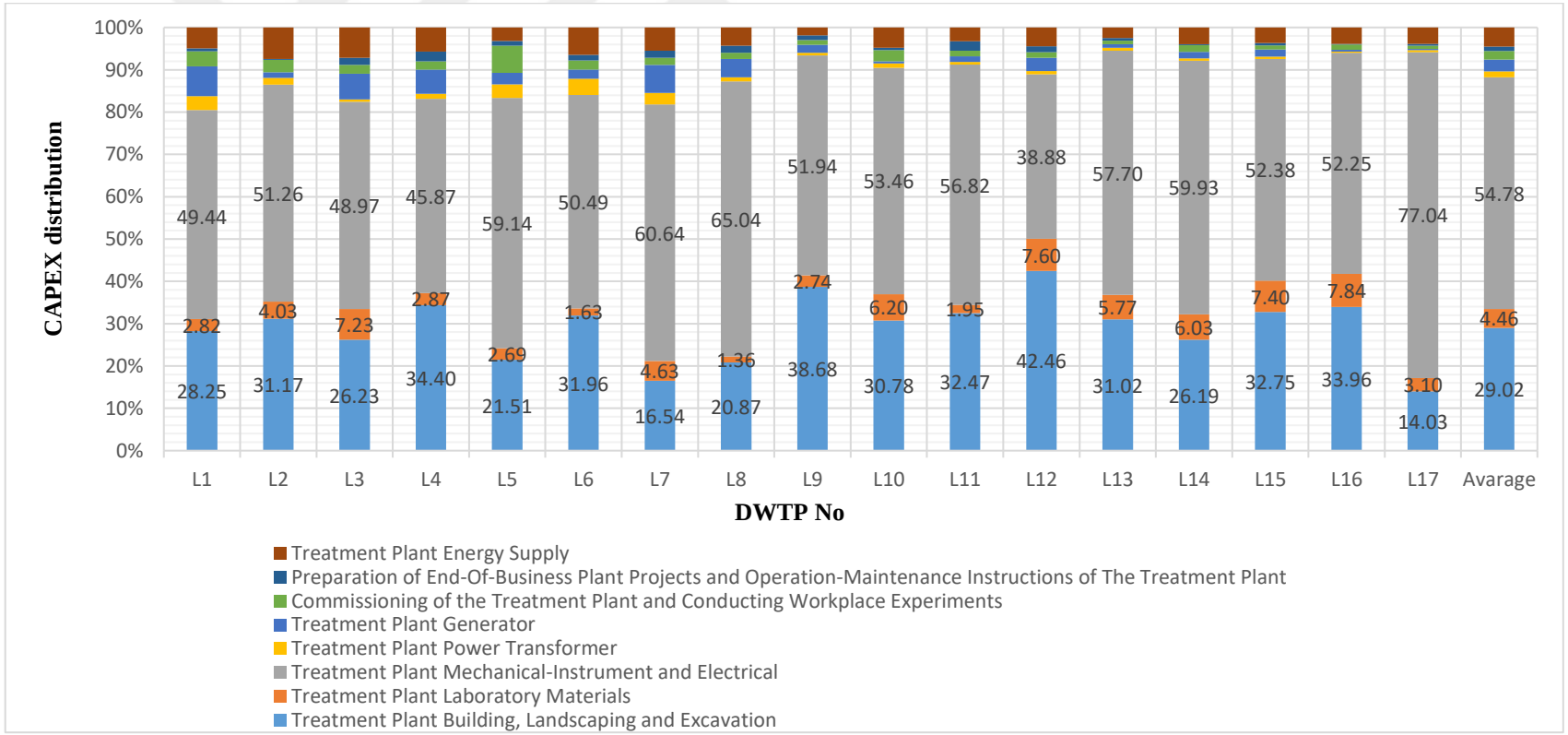

Figure 17 The cost distribution of the large capacity DWTPs with respect to components of total CAPEX

Figure 17 shows a bar chart for the large capacity DWTPs CAPEX components. The x-axis shows the DWTPs code and the y-axis shows the percentages (% of total expenses) of the CAPEX components. Similar to the CAPEX bar chart of small capacity plants, gray and blue colors account for approximately 80 percent of the entire column. Also, it shows that indirect costs are negligible which are green and dark navy colors in the figure.

5.1.3 CAPEX per unit product

Table 17 shows the CAPEX per m^3 of product water for the two capacity ranges investigated.

Table 17. Minimum, maximum and average CAPEX per m^3

	Small DWTPs (€/m^3)	Large DWTPs (€/m^3)
Minimum	0.011	0.004
Average	0.018	0.008
Maximum	0.026	0.012

According to the values in Table 17, the CAPEX of large capacity plants is 2.5 times cheaper than small capacity plants on average for every 1 m3 of water treated for 1 year. The results are supporting Ozgun et al. (2021) in some ways. While Ozgun et al. (2021) focused on the CAPEX and OPEX of WWTPs in Istanbul, their study also revealed a comparable in unit CAPEX, similar to the findings of this study."

5.2 OPEX

While calculating CAPEX, expenditures were found and converted to € in that year. After that, with the help of interest rates in Europe, bring them to 2022. On the other hand, OPEX calculations are different. Unlike CAPEX, the first step is finding the 2022 cost of the OPEX parameters (personnel, chemical, etc.). The main reason why

it is not done, as CAPEX is that since OPEX expenses are expenses during the operation, the expense items are specific to countries, so they are calculated based on TL based on 2022 expenses. CAPEX expense items, on the other hand, are calculated in € and calculated with Eurozone inflation, since the raw materials are sourced abroad. The data used for the results in the figures below are given collectively in Appendix E and F.

5.2.1 OPEX of the Small DWTPs

The most accurate conclusion that can be drawn from Figure 18 is that as the capacity increases, the OPEX also increases, but this increase shows a polynomial upward trend. On the other hand, as can be expected, the unit water treatment cost will decrease as the capacity increases and Figure 19 proves this prediction.

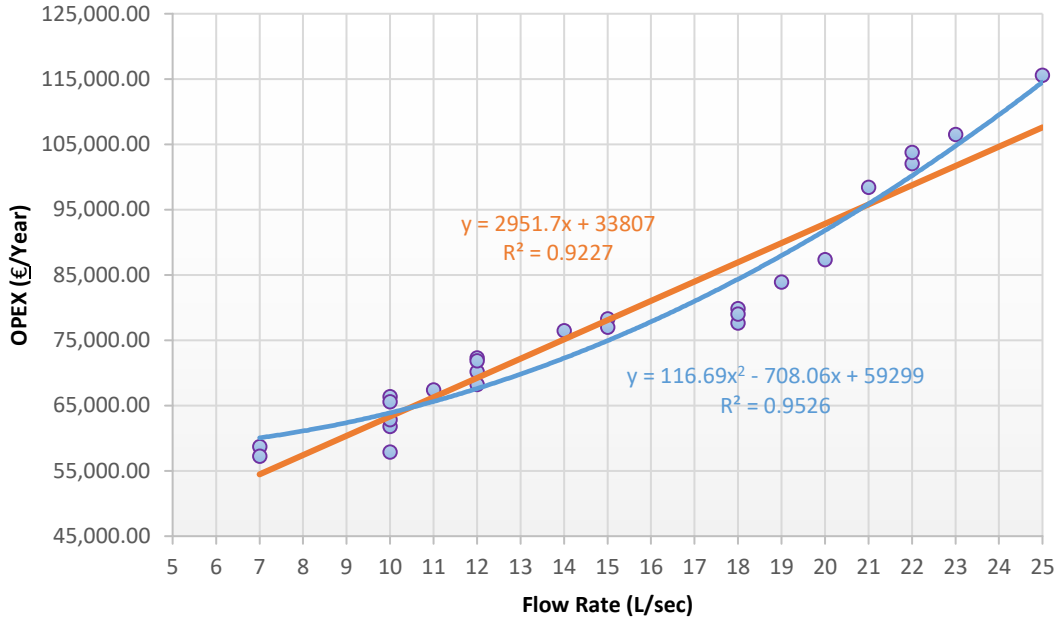

Figure 18. OPEX of small capacity DWTPs

Figure 18 shows the OPEX of plants in the range of 0-25 L/sec. In the graph, the x-axis shows the plant capacity as L/sec, and the y-axis shows the annual OPEX in €. In order to understand whether the rate of increase is polynomial or linear, the R^2 value was examined, and it was found that there is a polynomial increase, although the difference is small. The table in which the data are stored collectively is given in Appendix E.

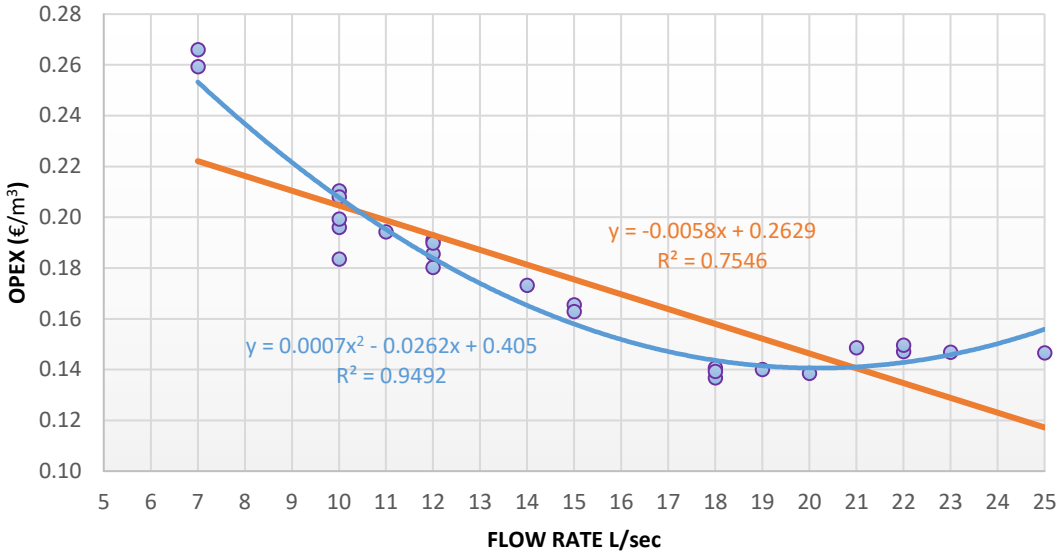

Figure 19. OPEX to treat 1 m^3 of water for small capacity DWTPs

Two different graphs have been created for the calculated unit cost value results for small capacity plants. The studies conducted in this context were found because of dividing the total OPEX value by capacity, and the results are given in Figure 19. There is a big difference between the two graphs, and it seems clear that there is a polynomial decrease.

When the two graphs are interpreted together, we reach the following result. As the capacities of small capacity plants increase, so do the yearly OPEX. The polynomial and linearity of this increase is very close. However, the unit water treatment cost decreases polynomial and reaching a balance point after 18 L/sec. Therefore, when considering the construction of more than one DWTP for nearby settlements, the design of a single large plant to meet the needs of all of them and the comparison of the two projects is an important element for the efficient use of resources. Of course, these results do not have to be correct for every situation. It is possible to encounter different results due to many variables such as geographical conditions. The plant

data used in these graphs are taken from plants with similar geography and similar conditions.

5.2.2 OPEX of the Large DWTPs

When analyzing the OPEX of large capacity DWTPs, Figure 20 illustrates an exponential increase in expenses corresponding to the capacity increase, displaying a trend that resembles a linear increase. In addition, although the €/m^3 in small capacity plants seems to decrease by accelerating and coming into balance, Figure 20 depicts a gradual and consistent decrease in large capacity plants.

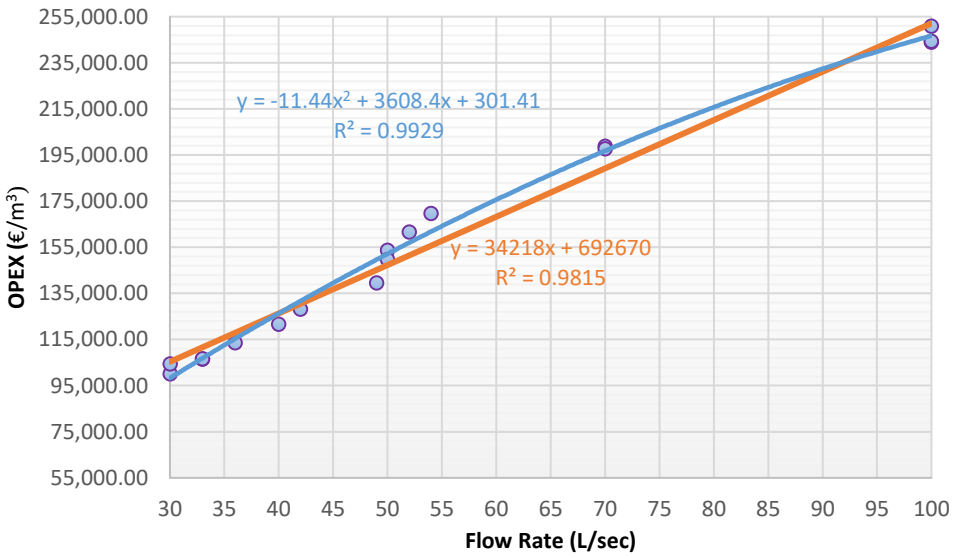

Figure 20. OPEX for large capacity DWTPs

Figure 20 shows the OPEX of plants in the range of 26-100 L/sec. In the graph, the x-axis shows the plant capacity, and the y-axis shows the annual OPEX in €. In order to understand whether the rate of increase is polynomial or linear, the R^2 value was examined, and it was found that there is a polynomial increase, although the

difference is small. The table in which the data are stored collectively is given in Appendix F.

According to Gallego-Valero et al. (2018), the average OPEX for the WWTPs in Spain varies from 0.14 to 0.27 €/m^3. This value is 0.095 €/m^3 for large capacity DWTPs and 0.176 €/m^3 for small capacity DWTPs in Turkey. This situation may show that the budget required to operate WWTPs is much higher than DWTPs.

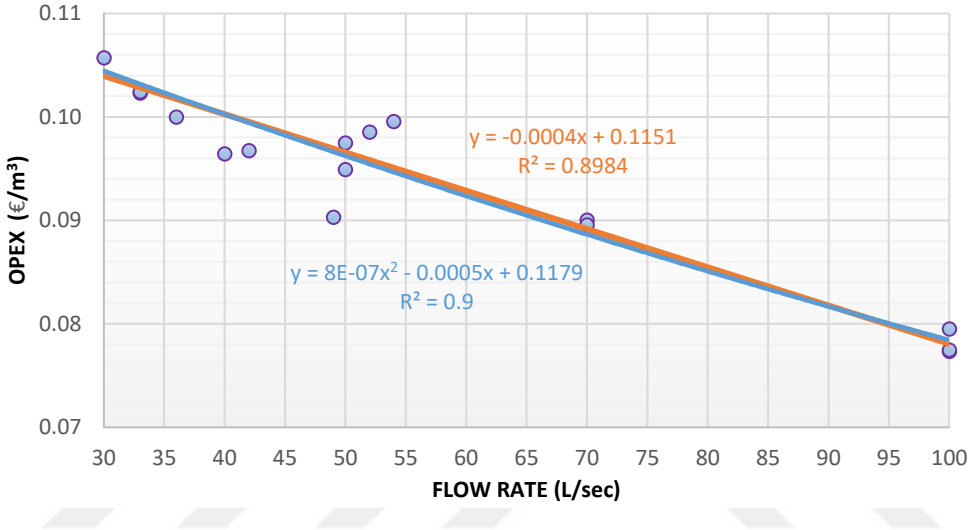

Figure 21. OPEX to treat 1 m^3 of water for large capacity DWTPs

In Figure 21, the x-axis shows the capacity of the plant, the y-axis shows the cost of the unit water. Two different graphs have been created for the calculated unit cost value results for large capacity plants. The graph shows that the maximum unit water cost for large capacity DWTP is close to the 0.11 € and the minimum unit water cost for large capacity DWTP is close to the 0.08 €.

When the two graphs are interpreted together, we reach the following result: as the capacities of large plants increase, the OPEX for the unit water treatment decreases but the decrease follows a polynomial trend. Therefore, when considering the construction of more than one water treatment plant for nearby settlements, the design of a single large facility to meet the needs of all of them becomes crucial for

the efficient use of resources. It should be noted that the results obtained from this study focus only on the expenses of the plants. Before a large plant is built instead of multiple small plants, it is essential to conduct a feasibility study in the light of information such as the extension of supply lines or the lines between intake structure and DWTP. It is possible to encounter different results due to many variables such as geographical conditions. The data of the treatment plants used in this study were taken from plants with similar geography and similar conditions, which prevents the formation of gap differences between the costs such as excavation between the plants.

5.3 TOTAL COST

The total annual expense account is calculated by adding the annual expense of the OPEX and CAPEX. This assessment is carried out separately for small and large capacity DWTPs.

5.3.1 Total Costs of Small DWTPs

The total cost calculations for both large and small capacity plants followed the same methodology. This approach uses the one-year flow rate to account for the total CAPEX on a per-unit water basis. To find unit CAPEX, the total CAPEX in the year of construction of the plant is divided by the annual flow rate, lifetime of the DWTP (35 years), and the CAPEX for the unit water flow is found.

OPEX, being an annual cost, was calculated separately. The total unit water cost was then determined by summing the unit water CAPEX and OPEX. The results are compiled in Table 18. The table shows that the minimum and maximum CAPEX to treat 1 m^3 of water per year range from 0.011 to 0.026 (€/ (m^3/year)), respectively. For the OPEX these values are higher and range from 0.137 to 0.266 (€/ (m^3/year)) respectively.

Table 18. Total costs of small capacity DWTPs

Name	Flow (m^3/year)	CAPEX (€)	CAPEX (€/ (m^3/year))	OPEX (€/ (m^3/year))	Total (€/ (m^3/year))
S1	220,752.00	194,962.45	0.025	0.266	0.291
S2	220,752.00	129,359.24	0.017	0.259	0.276
S3	315,360.00	155,068.83	0.014	0.184	0.198
S4	315,360.00	287,266.64	0.026	0.196	0.222
S5	315,360.00	208,152.85	0.019	0.199	0.218
S6	315,360.00	211,227.79	0.019	0.210	0.230
S7	315,360.00	193,886.34	0.018	0.208	0.226
S8	346,896.00	256,946.18	0.021	0.194	0.215
S9	378,432.00	220,043.29	0.017	0.180	0.197
S10	378,432.00	189,158.98	0.014	0.185	0.200
S11	378,432.00	194,279.32	0.015	0.191	0.206
S12	378,432.00	169,785.94	0.013	0.190	0.203
S13	378,432.00	229,424.09	0.017	0.173	0.190
S14	473,040.00	189,676.49	0.011	0.165	0.177
S15	473,040.00	184,208.82	0.011	0.163	0.174
S16	567,648.00	320,107.06	0.016	0.141	0.157
S17	567,648.00	340,171.03	0.017	0.137	0.154
S18	567,648.00	311,455.30	0.016	0.139	0.155
S19	599,184.00	420,838.54	0.020	0.140	0.160
S20	630,720.00	335,056.15	0.015	0.138	0.154
S21	662,256.00	443,014.04	0.019	0.149	0.168
S22	693,792.00	458,267.61	0.019	0.147	0.166
S23	693,792.00	495,696.51	0.020	0.150	0.170
S24	725,328.00	478,439.53	0.019	0.147	0.166
S25	788,400.00	632,272.99	0.023	0.147	0.170

5.3.2 Total Costs of the Large DWTPs

The total cost calculation results are compiled in Table 19 for large capacity DWTPs. As expected the unit total cost turned out to be much less compared to small capacity plants. The minimum and maximum for the total costs are 0.087 and 0.119 (€/ (m^3/year)) respectively.

Table 19. Total costs of large capacity DWTPs

Name	Flow (m^3/year)	CAPEX (€)	CAPEX (€/ (m^3/year))	OPEX (€/ (m^3/year))	Total (€/ (m^3/year))
L1	946,080.00	238,689.621	0.007	0.106	0.113
L2	946,080.00	295,863.425	0.009	0.110	0.119
L3	1,040,688.00	224,492.448	0.006	0.102	0.108
L4	1,040,688.00	265,018.570	0.007	0.102	0.110
L5	1,135,296.00	165,960.236	0.004	0.100	0.104
L6	1,261,440.00	324,065.881	0.007	0.096	0.104
L7	1,324,512.00	305,778.936	0.007	0.097	0.103
L8	1,545,264.00	329,243.693	0.006	0.090	0.096
L9	1,576,800.00	501,570.084	0.009	0.097	0.107
L10	1,576,800.00	430,400.068	0.008	0.095	0.103
L11	1,639,872.00	378,482.158	0.007	0.099	0.105
L12	1,702,944.00	455,766.288	0.008	0.100	0.107
L13	2,207,520.00	867,584.474	0.011	0.090	0.101
L14	2,207,520.00	771,936.275	0.010	0.090	0.100
L15	3,153,600.00	1,109,390.605	0.010	0.077	0.087
L16	3,153,600.00	1,213,000.000	0.011	0.077	0.088
L17	3,153,600.00	1,270,888.715	0.012	0.080	0.091

Unfortunately, as the focus is on total expenses for water treatment, there is no comparable study published for reference to compare the values in the table. However, Ozgun et al. (2021) conducted a similar study for İstanbul's WWTPs in 2021. According to their findings, the total CAPEX per unit volume of treated wastewater ranged from 0.013 to 0.054 €/m^3, while the OPEX ranged from 0.011 to

0.077 €/m^3. This suggests that in WWTPs, OPEX and CAPEX for treating unit volume of water are relatively close in value.

In contrast, for DWTPs, OPEX is likely to be more dominant for treating a unit volume of water compared to WWTPs. There are two main reasons for this difference: plant capacities and treatment types. Due to these factors, CAPEX components are likely to occupy a larger percentage of total expenses in DWTPs.

Firstly, WWTPs typically require larger areas for process implementation compared to DWTPs. For example, DWTPs may only require 3-4 steps cascade aeration for treatment, whereas WWTPs often need wider aerobic and sometimes anaerobic units to accommodate bacterial processes. Additionally, due to hydraulic considerations, WWTPs are frequently located near streams and at lower elevations. This necessitates flatter land compared to DWTPs, which can lead to higher excavation costs for WWTP construction (Ozgun et al. (2021).

Friedler & Pisanty (2006) conducted a similar study on municipal WWTPs. They observed that while OPEX for municipal WWTPs tends to decrease as plant capacity increases, the OPEX share of total costs actually increases. This trend appears to be similar for DWTPs, as shown in Table 18 and Table 19. The data suggests that OPEX follows a decreasing trend with increasing capacity in DWTPs as well. However, unlike municipal WWTPs, for DWTPs, OPEX remains the dominant component regardless of plant capacity (Friedler & Pisanty, 2006).

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This study examines the CAPEX, OPEX and total costs of 42 DWTPs in the Turkish municipalities. Additionally, the study explores the relationship between these expenditures and DWTPs' capacities. Within the scope of this thesis, the CAPEX and OPEX of the DWTPs up to 100 L/s of the municipalities in Turkey were collected. These plants are divided into small and large capacity according to their capacities based on 0-25 and 26-100 L/sec and the number of plants. While making the CAPEX evaluations, the difference between the construction years of the plants is equalized with the € exchange rate in that year in Turkey, and inflation in Euro region. The raw data which are used in CAPEX and the adjusted data after calculations are given in Appendices C, and 0. While OPEX calculations are performed, the components of the OPEX (electricity, chemicals, etc.) used during the operation of the plant were multiplied by the unit prices for the year 2022.

As a result of OPEX evaluations, it has been determined that large capacity plants (26-100 L/sec) have an expense ranging from $4.09x10^6$ TL/year to $1.63x10^6$ TL/year. With the average exchange rate in 2022, these values are equal to $1x10^5$ and 2.50 x 10^5 €/year. On the other hand, for small capacity plants (0 -25 L/sec), these costs are ranging from 9.34 x 10^5 TL/year to 18.86 x 10^5 TL/year. With the average exchange rate in 2022, these values are equal to 5.72 x 10^4 and 11.55 x 10^4 €/year. Since the one of the most important reasons for calculating the OPEX is to see the total OPEX spent on treating 1 m^3 of water, the OPEX values are divided by the operating flows of the plant, and the OPEX required for treating 1 m^3 of water is calculated. These values vary between 2.39 TL (0.14 €) to 4.34 TL (0.27 €) in large capacity DWTPs and 1.26 TL (0.08 €) to 1.80 TL (0.11 €) in small capacity DWTPs. Although the OPEX increases as the capacity of the plants increases, it is almost twice expensive to treat 1 m^3 of water for a small capacity plant.

As a result of CAPEX evaluations, it has been determined that small capacity plants have an expense ranging from $1.29x10^5$ to $6.32x10^5$ €. On the other hand, large capacity plants have an expense ranging from $1.66x10^5$ to $12.7x10^5$ €. Unlike OPEX, CAPEX is a one-time expense item with more diverse components. In the Table 8, the direct and indirect expenses in the CAPEX of the plants are summarized. If CAPEX is considered as only direct and indirect expenses (Table 13 and Table 15), direct expenses account for close to 95% of the CAPEX. More detail components in direct and indirect expenses are given for small and large capacity DWTPs in Figure 12 and Figure 17 respectively. As can be seen from the figures, the highest CAPEX component is mechanical-instrument and electrical expenses, which account for almost half of the plant expenses in both large and small capacity DWTPs.

In the calculation of total costs, OPEX and CAPEX to treat 1 m^3 of raw water were calculated and it was concluded how much budget is required for the treatment of 1 m^3 of water in total. Since CAPEX is a one-time expense paid during the planned operating period of the DWTP, 1-year CAPEX was collected with OPEX to create a total cost for one year. To summation of the OPEX and CAPEX, CAPEX data divided by 35 years, which is the operating period of the plant, and collected with OPEX. While small capacity plants have the minimum 0.15 (€/ (m^3/year)), and the maximum 0.29 (€/(m^3/year)) to treat 1 m^3 of water for a year, large capacity plants have a minimum expenditure of 0.087 (€/(m^3/year)) and maximum of 0.119 (€/ (m^3/year)) to treat 1 m^3 of water for a year. According to these results, water treatment of small capacity plants is approximately 1.7 times more costly compared to large capacity plants.

In the future, this thesis study can be developed in different ways. For example, this study is the calculation of the overall OPEX for a DWTP, which means that the expenses belong to the entire plant not the processes individually. If the process units are calculated separately, it can be determined which unit has the higher expense in the total plant OPEX and CAPEX. In addition, by increasing the number of plants, it can be found out which regions have more expenses by comparing the expenses of

the plants in seven regions of Turkey with each other, both as CAPEX and OPEX. This helps to see the effect of climate and geography on drinking water treatment. In addition, the plants within the scope of this thesis consist of conventional type (ventilation, fast-slow mixers, settling tanks, chlorination) plants. By adding DWTP with RO or ion exchange processes, the energy, OPEX and CAPEX of advanced treatment process plants can be examined comparatively. Which advanced purification processes are more suitable, in which capacity (NF-RO etc.) can be found more clearly with this way. This will allow us to make a viable process selection of a plant in advance for the future. In addition, according to this thesis, construction costs increase in direct proportion to the capacity in plants, but they decrease much faster than the rate of increase of expenditure per unit of water, and the income from the sale of water has not been included in the evaluations.

Different approaches can be explored in the future to further develop this situation. For example, break-even point evaluations could be involved. Break-even analysis is a useful method to understand the relationship between costs and returns. This analysis identifies the point at which an investment will generate a positive return (Gutierrez, 1990). In our study, this refers to the point at which all CAPEX and OPEX are equal to the total sales (revenues). After reaching this point, the revenues generated during the specified period become profits. Another way of developing this thesis is about the feasibility. Within the scope of this thesis, it is understood that it is much more profitable to build one and a large facility than to build more than one small facility. Within the scope of this thesis, it has been seen that it is much more profitable to build one and a large facility than to build more than one small facility. However, there are different extra expenditures such as prolongation of water supply from the raw-water intake part to the DWTP and water supply from DWTP to the municipalities since it will serve to the larger areas. According to the distance and capacities, it may be clarified that when it is more appropriate to build a plant that will be used jointly, to what capacity and how far.

REFERENCES

Akgiray, Ö., Üniversitesi, M., Mühendisliği, Ç., & Göztepe, B. (2003). İÇME SULARININ DEZENFEKSİYONUNDA TEMEL PRENSİPLER.

Albolafio, S., Marín, A., Allende, A., García, F., Simón-Andreu, P. J., Soler, M. A., & Gil, M. I. (2022). Strategies for mitigating chlorinated disinfection byproducts in wastewater treatment plants. Chemosphere, 288. https://doi.org/10.1016/j.chemosphere.2021.132583

Arif, A. U. A., Sorour, M. T., & Aly, S. A. (2020). Cost analysis of activated sludge and membrane bioreactor WWTPs using CapdetWorks simulation program: Case study of Tikrit WWTP (middle Iraq). Alexandria Engineering Journal, 59(6), 4659–4667. https://doi.org/10.1016/J.AEJ.2020.08.023

Association, A. W. W., & Edzwald, J. (2010, December 6). Water Quality & Treatment: A Handbook on Drinking Water. McGraw Hill Professional.

Baruth, E. E., American Society of Civil Engineers., & American Water Works Association. (2005). Water treatment plant design.

Bratby, J. (2006, October 15). Coagulation and Flocculation in Water and Wastewater Treatment. IWA Publishing.

Boccelli, D.L., Small, M.J. and Diwekar, U.M. (2007) 'Drinking water treatment plant design incorporating variability and uncertainty', Journal of Environmental Engineering, 133(3), pp. 303–312. doi:10.1061/(asce)0733-9372(2007)133:3(303).

Boyden, B. H., Banh, D. T., Huckabay, H. K., & Fernandes, J. B. (1992, May). Using Inclined Cascade Aeration to Strip Chlorinated VOCs From Drinking Water. Journal AWWA, 84(5), 62–69.

Carey, K. (2014). Cost Function Estimates. Encyclopedia of Health Economics, 121–125.

Çakmakçı, M., Özkaya, B., Yetilmezsoy, K., & Demir, S. (2013). Principles of Design and Operation of Water Treatment Plants.

Ćetković, J., Knežević, M., Lakić, S., Žarković, M., Vujadinović, R., Živković, A., & Cvijović, J. (2022, January 5). Financial and Economic Investment Evaluation of Wastewater Treatment Plant. Water, 14(1), 122.

Charcosset, C. (2012, January 25). Membrane Processes in Biotechnology and Pharmaceutics. Elsevier.

Committee, N. R. C. (US) S. D. W. (1982). Elements of Public Water Supplies.

Directive - 2020/2184 - EN - EUR-Lex. (2020).

Duah, D., & Syal, M. G. M. (2017, November). Direct and Indirect Costs of Change Orders. Practice Periodical on Structural Design and Construction, 22(4).

Echevarría, C., Pastur, M., Valderrama, C., Cortina, J., Vega, A., Mesa, C., & Aceves, M. (2022, April). Techno-economic assessment of decentralized polishing schemes for municipal water reclamation and reuse in the industrial sector in costal semiarid regions: The case of Barcelona (Spain). Science of the Total Environment, 815, 152842.

EUR-Lex - 31998L0083 - EN - EUR-Lex. (n.d.). Retrieved December 25, 2023, from https://eur-lex.europa.eu/Legal-content/EN/TXT/?uri=celex%3A31998L0083

Friedler, E. and E. Pisanty (2006), Effects of Design Flow and Treatment Level on Construction and Operation Costs of Municipal Wastewater Treatment Plants and Their Implications on Policy Making, Water Research, 40, 3751-3758. https://doi.org/10.1016/j.watres.2006.08.015.

Fujioka, T., Ueyama, T., Mingliang, F., & Leddy, M. (2019, August). Online assessment of sand filter performance for bacterial removal in a full-scale drinking water

treatment plant. Chemosphere, 229, 509–514. https://doi.org/10.1016/j.chemosphere.2019.04.197

Giresunlu, E., Özüdoğru, A., Yaycılı, F., Uflaz, H., GÜMÜŞKAYA, C., Sarıoğlu, M., & Karaaslan, Y. (2019, July 12). Drinking Water Treatment Plants in Turkey and Determination of Revision Needs. Turkish Journal of Water Science and Management, 3(2), 44–57.

Gutierrez, P., & Dalsted, N. L. (1990). Break-even method of investment analysis. Colorado State University Cooperative Extension.

Handbook for the Economic Analysis of Water Supply Projects. (1999, January 1).

Horváthová, E. (2022). Analysis of Drinking Water treatment costs – with an Application to Groundwater Purification Valuation. One Ecosystem 7: E82125, 7, e82125-. https://doi.org/10.3897/ONEECO.7.E82125

Hinomoto, H. (1977, December). Capital cost functions of a surface water treatment plant and its components. Water Resources Research, 13(6), 873–876.

Hoff J.C., Akin E.W. Microbial resistance to disinfectants: mechanisms and significance. Environ. Health Prospect 1986; 69:7–13.

Hunter, J., Jagals, P., & Pond, K. (2011). Estimating costs of small-scale water-supply interventions. Valuing Water, Valuing Livelihoods: Guidance on Social Cost-Benefit Analysis of Drinking-Water Interventions, with Special Reference to Small Community Water Supplies, 149–166.

Ilbank. (2013). Drinking Water Treatment Plant Project Process Specification.

Jacimaria, B., Saria, B., & Sajjad, A. (2020). Water -energy -carbon nexus approach for sustainable large-scale drinking water treatment operation _ Elsevier Enhanced Reader. Journal of Hydrology.

Kawamura, Susumu. (2000). Integrated design and operation of water treatment facilities. 691.

Khalifa, A., Bayoumi, S., & El Monayeri, O. (2011, January 1). Mathematical modeling of aeration efficiency and dissolved oxygen provided by stepped cascade aeration. Water Science and Technology, 63(1), 1–9. https://doi.org/10.2166/wst.2011.001

Lin, L., Yang, H., & Xu, X. (2022, June 30). Effects of Water Pollution on Human Health and Disease Heterogeneity: A Review. Frontiers in Environmental Science, 10.

Logsdon,G., Hess,A., Horsley, M. (1999) "Chapter 3: Guide to Selection Of Water Treatment Processes", Water Quality and Treatment Processes", Water Quality and Treatment, Editor: Letterman R.D., p. 3.1-3.26, McGraw-Hill Publ., 5th ed., ISBN: 0-07-001659-3, USA.

Ministry of Agriculture and Forestry. (2019). Regulation on the Quality and Treatment of Drinking Water Supplied

Ministry of Agriculture and Forestry (2015) Surface Water Quality Regulation.

Okta Virtania, L., & Siregar, S. V. (2017). The Effect of Environmental Disclosure on Cost of Equity.

Ozgun, H., Cicekalan, B., Akdag, Y., Koyuncu, I., & Ozturk, I. (2021). Comparative evaluation of cost for preliminary and tertiary municipal wastewater treatment plants in Istanbul. Science of the Total Environment, 778, 146258.

Rauen, W. B., Angeloudis, A., & Falconer, R. A. (2012, November). Appraisal of chlorine contact tank modelling practices. Water Research, 46(18), 5834–5847.

Sayato, Y. (1989). WHO guidelines for drinking-water quality. Eisei Kagaku, 35(5), 307–312.

Sharma, J. R. (2010). Development of a Preliminary Cost Estimation Method for Water Treatment Plants.

Singh, R., & Hankins, N. P. (2016). Introduction to Membrane Processes for Water Treatment. Emerging Membrane Technology for Sustainable Water Treatment, 15–52.

Smol, M. (2018). The use of membrane processes for the removal of phosphorus from wastewater. Desalination and Water Treatment, 128, 397–406.

Squire, L., Van Der Tak, H. G., & Bank, W. (1975, January 1). Economic Analysis of Projects. World Bank Publications.

Stevie, R. G. and Clark, R. M. (1980), Package Water Treatment Plants, Volume II - A Cost Evaluation, U.S. Environmental Protection Agency, Cincinnati, OH 45268, EPA-600/2-008b.

TCMB - Gösterge Niteliğindeki Merkez Bankası Kurları. (n.d.). https://www.tcmb.gov.tr/wps/wcm/connect/TR/TCMB+TR/Main+Menu/Istatistikler/Doviz+Kurlari/Gosterge+Niteligindeki+Merkez+Bankasi+Kurlarii/

Themido, I., Arantes, A., Fernandes, C., & Guedes, A. P. (2000, October). Logistic costs case study—an ABC approach. Journal of the Operational Research Society, 51(10), 1148–1157.

Tiggeloven, T., et al., 2020: Global-scale benefit–cost analysis of coastal flood adaptation to different flood risk drivers using structural measures. Nat. Hazards Earth Syst. Sci. , 20 (4), 1025–1044.

Topçu, A. (2004). Development of cost index for water treatment plants

Turner, R. Kerry. (2004). Economic valuation of water resources in agriculture : from the sectoral to a functional perspective of natural resource management. 187.

United Nations. (1992). United Nations Conference on Environment & Development.

Veljkovic, N., & Mitrovic, G. (1997). Lamella sedimentation application in technology of drinking water treatment. Voda i sanitarna tehnika (Yugoslavia), 27(5).

Voutchkov, N. (2017). Conditioning of Saline Water. Pretreatment for Reverse Osmosis Desalination, 113–135. https://doi.org/10.1016/b978-0-12-809953-7.00006-1

Whittington, D., & Michael Hanemann, W. (2006) The Economic Costs and Benefits of Investments in Municipal Water and Sanitation Infrastructure: A Global Perspective.

White, G.C., ed. (1986) the Handbook of Chlorination, 2nd ed., New York, Van Nostrand Reinhold.

Xie, Y., Zeng, L., Wang, P., Wu, X., & Feng, T. (2022). Water cost for water purification: Renewability assessment of a typical wastewater treatment plant in China ☆. Journal of Cleaner Production, 349.

Young, R. A., & Loomis, J. B. (2014, July 23). Determining the Economic Value of Water. https://doi.org/10.4324/9780203784112

Zessner, M., Lampert, C., Kroiss, H., & Lindtner, S. (2010, July 1). Cost comparison of wastewater treatment in Danubian countries. Water Science and Technology, 62(2), 223–230. https://doi.org/10.2166/wst.2010.271

APPENDICES

A. Legislative Quality Requirements Concerning Drinking Waters

Table A 1. Minimum requirements for parametric values used to assess the quality of water intended for human consumption (Directive - 2020/2184 - EN - EUR-Lex, n.d.)

Microbiological parameters			
Parameter	**Parametric Value**	**Unit**	**Notes**
Intestinal enterococci	0	Number/100 mL	For water put into bottles or containers, the unit is number/250 ml.
Escherichia Coli	0	Number/100 mL	For water put into bottles or containers, the unit is number/250 mL.
Chemical parameters			
Parameter	**Parametric Value**	**Unit**	**Notes**
Acrylamide	0.10	µg/L	The parametric value of 0,10 µg/L refers to the residual monomer concentration in the water as calculated according to specifications of the maximum release from the corresponding polymer in contact with the water.
Antimony	10	µg/L	
Arsenic	10	µg/L	
Benzene	1	µg/L	
Benzo(a)pyrene	0.010	µg/L	
Bisphenol A	2.5	µg/L	
Boron	1.5	µg/L	A parametric value of 2,4 mg/L shall be applied when desalinated water is the predominant water source of the supply system concerned or in regions where geological conditions could lead to high levels of boron in groundwater.
Bromate	10	µg/L	
Cadmium	5.0	µg/L	

Chlorate	0.25	mg/L	A parametric value of 0,70 mg/L shall be applied where a disinfection method that generates chlorate, in particular chlorine dioxide, is used for disinfection of water intended for human consumption.
Chlorite	0.25	mg/L	A parametric value of 0,70 mg/L shall be applied where a disinfection method that generates chlorite, in particular chlorine dioxide, is used for disinfection of water intended for human consumption.
Chromium	25	µg/L	The parametric value of 25 µg/L shall be met, at the latest, by 12 January 2036. The parametric value for chromium until that date shall be 50 µg/L.
Copper	2.0	mg/L	
Cyanide	50	µg/L	
1,2-dichloroethane	3.0	µg/L	
Epichlorohydrin	0.10	µg/L	The parametric value of 0,10 µg/L refers to the residual monomer concentration in the water as calculated according to specifications of the maximum release from the corresponding polymer in contact with the water.
Fluoride	1.5	mg/L	
Haloacetic acids (HAAs)	60	µg/L	This parameter shall be measured only when disinfection methods that can generate HAAs are used for the disinfection of water intended for human consumption. It is the sum of the following five representative substances: monochloro-, dichloro-, and trichloro-acetic acid, and mono- and dibromo-acetic acid.
Lead	5	µg/L	The parametric value of 5 µg/L shall be met, at the latest, by 12 January 2036. The parametric value for lead until that date shall be 10 µg/L.
Mercury	1.0	µg/L	
Microcystin-LR	1.0	µg/L	This parameter shall be measured only in the event of potential blooms in source

			water (increasing cyanobacterial cell density or bloom forming potential).
Nickel	20	µg/L	
Nitrate	50	mg/L	
Nitrite	0.50	mg/L	
Pesticides	0.10	µg/L	The parametric value of 0,10 µg/L shall apply to each individual pesticide. In the case of aldrin, dieldrin, heptachlor and heptachlor epoxide, the parametric value shall be 0,030 µg/L.
Pesticides Total	0.50	µg/L	'Pesticides Total' means the sum of all individual pesticides, detected, and quantified in the monitoring procedure.
PFAS Total	0.50	µg/L	'PFAS Total' means the totality of per- and polyfluoroalkyl substances.
Sum of PFAS	0.10	µg/L	
Polycyclic aromatic hydrocarbons	0.10	µg/L	Sum of concentrations of the following compounds: benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(ghi)perylene, and indeno(1,2,3-cd)pyrene.
Selenium	20	µg/L	A parametric value of 30 µg/L shall be applied for regions where geological conditions could lead to high levels of selenium in groundwater.
Tetrachloroethene and Trichloroethene	10	µg/L	The sum of concentrations of these two parameters.
Trihalomethanes Total	100	µg/L	Where possible, without compromising disinfection, Member States shall strive for a lower parametric value.
Uranium	30	µg/L	
Vinyl chloride	0.50	µg/L	The parametric value of 0,50 µg/L refers to the residual monomer concentration in the water as calculated according to specifications of the maximum release from the corresponding polymer in contact with the water.
Indicator Parameters			

Parameter	Parametric Value	Unit	Notes
Aluminum	200	µg/L	
Ammonium	0.50	mg/L	
Chloride	250	mg/L	The water should not be corrosive.
Clostridium perfringens including spores	0	Number/100ml	This parameter shall be measured if the risk assessment indicates that it is appropriate to do so.
Color	Acceptable to consumers and no abnormal change		
Conductivity	2500	µS cm^{-1} at 20 °C	The water should not be aggressive.
Hydrogen ion concentration	≥ 6.5 and ≤ 9.5	pH units	The water should not be aggressive.
Iron	200	µg/L	
Manganese	50	µg/L	
Odor	Acceptable to consumers and no abnormal change		
Oxidisability	5.0	mg/L O_2	This parameter need not be measured if the parameter TOC is analysed.
Sulphate	250	mg/L	The water should not be corrosive.
Sodium	200	mg/L	
Taste	Acceptable to consumers and no abnormal change		
Colony count 22° C	No abnormal change		
Coliform bacteria	0	number/100ml	For water put into bottles or containers, the unit is number/250 ml.
Total organic carbon (TOC)	No abnormal change		This parameter need not be measured for supplies of less than 10 000 m^3 a day.
Turbidity	Acceptable to consumers and no abnormal change		

Water should not be aggressive or corrosive. This applies particularly to water undergoing treatment (demineralization, softening, membrane treatment, reverse osmosis, etc.).
Where water intended for human consumption is derived from treatment that significantly demineralizes or softens water, calcium and magnesium salts could be added to condition the water in order to reduce any possible negative health impact, as well as to reduce the corrosiveness or aggressivity of water and to improve taste. Minimum concentrations of calcium and magnesium or total dissolved solids in softened or demineralized water could be established taking into account the characteristics of water that enters those processes.

Parameter	**Parametric Value**	**Unit**	**Notes**
Legionella	< 1000	CFU/L	
Lead	10	µg/L	Member States should use their best endeavours to achieve the lower value of 5 µg/L by 12 January 2036.

Table A 2. Quality Criteria of Continental Surface Water Resources According to Their Classes in Terms of General Chemical and Physicochemical Parameters (Regulation on the Quality of Surface Waters, Official Gazette dated 30.11.2012, numbered 28483)

Water Quality Parameters	**Water Quality Classes**		
	I (very good)	**II (good)**	**III (moderate)**
Color (m^{-1})	RES 436 nm: ≤ 1.5 RES 525 nm: ≤ 1.2 RES 620 nm: ≤ 0.8	RES 436 nm: 3 RES 525 nm: 2.4 RES 620 nm: 1.7	RES 436 nm: > 4.3 RES 525 nm: > 3.7 RES 620 nm: 2.5
pH	6-9	6-9	6-9
Conductivity (µS/cm)	< 400	1000	> 1000
Oil and Grease (mg/L)	< 0.2	0.3	> 0.3
Dissolved oxygen (mg/L)	> 8	6	< 6
Chemical oxygen demand (COD) (mg/L)	< 25	50	> 50
Biochemical oxygen demand (BOD_5) (mg/L)	< 4	8	>8
Ammonium nitrogen (mg NH_4^+-N/L)	< 0.2	1	>1
Nitrate nitrogen (mg NO_3^--N/L)	< 3	10	> 10
Total kjeldahl-nitrogen (mg N/L) (b)	< 0.5	1.5	> 1.5
Total nitrogen (mg N/L) (c)	< 3.5	11.5	> 11.5
Ortho phosphate phosphor (mg o-PO_4-P/L)	< 0.05	0.16	> 0.16
Total phosphorus (mg P/L)	< 0.08	0.2	> 0.2
Fluoride (µg/L)	≤ 1000	1500	> 1500
Mangan (µg/L)	≤ 100	500	> 500
Selenium (µg/L)	≤ 10	15	> 15
Sulfur (µg/L)	≤ 2	5	> 5

B. Breakdown of CAPEX

Table B 1 Breakdown of CAPEX (as % of the total CAPEX) for Small-Capacity DWTPs

DWTP Codes	Treatment Plant Building, Landscaping and Excavation	Treatment Plant Laboratory Materials	Treatment Plant Mechanical-Instrument and Electrical	Treatment Plant Power Transformer	Treatment Plant Generator	Commissioning of the Treatment Plant and Conducting Workplace Experiments	Preparation of End-Of-Business Plant Projects and Operation-Maintenance Instructions of The Treatment Plant	Treatment Plant Energy Supply	Total
S1	44.01	7.70	64.20	0.96	2.25	1.77	0.96	0.98	100.00
S2	27.48	8.38	52.61	1.68	1.68	2.68	2.6	2.82	100.00
S3	13.56	12.11	65.05	1.21	4.68	1.37	1.61	0.40	100.00
S4	29.01	8.24	47.63	1.65	6.50	1.41	1.36	4.20	100.00
S5	22.40	6.64	58.08	2.49	3.32	1.99	0.37	4.72	100.00
S6	32.31	2.39	55.05	1.80	1.20	2.39	2.39	2.47	100.00

DWTP Codes	Treatment Plant Building, Landscaping and Excavation	Treatment Plant Laboratory Materials	Treatment Plant Mechanical-Instrument and Electrical	Treatment Plant Power Transformer	Treatment Plant Generator	Commissioning of the Treatment Plant and Conducting Workplace Experiments	Preparation of End-Of-Business Plant Projects and Operation-Maintenance Instructions of The Treatment Plant	Treatment Plant Energy Supply	Total
S7	14.25	4.27	66.95	0.28	5.98	2.85	2.56	2.85	100.00
S8	31.82	9.79	53.84	0.39	1.47	1.47	0.73	0.49	100.00
S9	25.02	5.21	60.66	1.04	3.13	2.34	1.25	1.36	100.00
S10	20.75	4.72	61.32	1.89	2.83	1.89	1.89	4.72	100.00
S11	31.93	5.11	51.09	2.55	3.58	1.28	1.28	3.19	100.00
S12	19.32	4.83	64.41	2.42	1.61	2.74	0.81	3.86	100.00
S13	35.01	3.02	51.46	2.12	5.31	0.21	0.21	2.65	100.00
S14	27.48	9.25	46.26	2.50	7.03	1.98	0.88	4.63	100.00
S15	22.50	3.75	57.50	1.25	6.25	2.50	1.25	5.00	100.00
S16	34.57	4.19	46.62	2.46	7.33	2.62	0.63	1.57	100.00
S17	27.60	13.50	46.53	2.16	3.19	1.04	0.57	5.40	100.00
S18	26.08	0.91	65.19	0.65	2.62	1.30	0.65	2.61	100.00

DWTP Codes	Treatment Plant Building, Landscaping and Excavation	Treatment Plant Laboratory Materials	Treatment Plant Mechanical-Instrument and Electrical	Treatment Plant Power Transformer	Treatment Plant Generator	Commissioning of the Treatment Plant and Conducting Workplace Experiments	Preparation of End-Of-Business Plant Projects and Operation-Maintenance Instructions of The Treatment Plant	Treatment Plant Energy Supply	Total
S19	25.28	5.95	56.51	0.59	9.67	0.89	0.37	0.74	100.00
S20	29.63	1.65	61.73	0.82	2.47	0.82	1.98	0.91	100.00
S21	27.78	4.94	55.56	1.85	3.09	1.85	1.85	3.09	100.00
S22	34.90	10.05	48.93	0.93	3.01	0.75	0.37	1.06	100.00
S23	44.01	5.23	48.25	0.48	0.87	0.58	0.29	0.29	100.00
S24	33.65	4.75	57.22	0.46	1.52	0.86	0.34	1.18	100.00
S25	36.53	6.82	48.70	1.62	2.35	0.81	0.81	2.35	100.00
Average	**27.76**	**6.14**	**55.65**	**1.45**	**3.72**	**1.62**	**1.12**	**2.54**	**100.00**

Table B 2 Breakdown of CAPEX (as % of the total CAPEX) for Large-Capacity DWTPs

DWTP Codes	Treatment Plant Building, Landscaping and Excavation	Treatment Plant Laboratory Materials	Treatment Plant Mechanical-Instrument and Electrical	Treatment Plant Power Transformer	Treatment Plant Generator	Commissioning of the Treatment Plant and Conducting Workplace Experiments	Preparation of End-Of-Business Plant Projects and Operation-Maintenance Instructions of The Treatment Plant	Treatment Plant Energy Supply	Total
L1	28.25	2.82	49.44	3.25	7.06	3.53	0.71	4.94	100.00
L2	31.17	4.03	51.26	1.65	1.28	2.98	0.18	7.45	100.00
L3	26.44	7.29	49.36	0.56	6.09	2.16	0.88	7.21	100.00
L4	25.64	3.20	38.46	1.28	6.41	15.40	3.20	6.41	100.00
L5	30.74	2.56	56.35	3.07	2.56	0.61	1.02	3.07	100.00
L6	29.76	1.59	49.52	3.72	2.13	4.25	2.66	6.38	100.00
L7	16.54	4.63	60.64	2.76	6.62	1.65	1.65	5.51	100.00
L8	21.31	1.38	66.41	1.00	4.37	0.83	0.28	4.43	100.00
L9	39.07	2.77	52.46	0.68	1.87	0.88	0.38	1.89	100.00
L10	30.78	6.20	53.46	1.07	0.48	2.67	0.53	4.81	100.00

DWTP Codes	Treatment Plant Building, Landscaping and Excavation	Treatment Plant Laboratory Materials	Treatment Plant Mechanical-Instrument and Electrical	Treatment Plant Power Transformer	Treatment Plant Generator	Commissioning of the Treatment Plant and Conducting Workplace Experiments	Preparation of End-Of-Business Plant Projects and Operation-Maintenance Instructions of The Treatment Plant	Treatment Plant Energy Supply	Total
L11	33.11	1.99	57.95	0.66	1.32	0.66	0.99	3.31	100.00
L12	42.94	7.68	39.32	0.75	3.21	0.90	0.68	4.52	100.00
L13	31.15	5.80	57.95	0.71	0.87	0.80	0.19	2.54	100.00
L14	25.89	5.96	59.22	0.51	1.57	2.75	0.18	3.92	100.00
L15	32.94	7.44	52.68	0.59	1.68	0.66	0.31	3.71	100.00
L16	33.96	7.84	52.25	0.26	0.39	1.31	0.08	3.92	100.00
L17	14.07	3.11	77.27	0.45	0.28	0.76	0.18	3.87	100.00
Average	**29.04**	**4.49**	**54.35**	**1.35**	**2.83**	**2.52**	**0.83**	**4.58**	**100.00**

C. Adjusted CAPEX for Small Capacity DWTPs

Table C 1 CAPEX for the year of construction and adjusted to 2022 for the small capacity DWTPs

Number	DWTP Code/Year	Flow (L/sec)	CAPEX (TL)	CAPEX (€)	CAPEX (€/(L/sec))
1	S1 / 2020	7	1,557,750.00	193,991.28	27,713.04
	S1 / 2021	7		194,476.26	27,782.32
	S1 / 2022	7		194,962.45	27,851.78
2	S2 / 2012	7	298,400.00	129,739.13	18,534.16
	S2 / 2013	7		131,685.22	18,812.17
	S2 / 2014	7		132,844.05	18,977.72
	S2 / 2015	7		133,309.00	19,044.14
	S2 / 2016	7		133,708.93	19,101.28
	S2 / 2017	7		134,043.20	19,149.03
	S2 / 2018	7		134,378.31	19,196.90
	S2 / 2019	7		134,714.25	19,244.89
	S2 / 2020	7		135,051.04	19,293.01
	S2 / 2021	7		135,388.67	19,341.24
	S2 / 2022	7		135,727.14	19,389.59
3	S3 / 2020	10	1,239,000.00	154,296.39	15,429.64
	S3 / 2021	10		154,682.13	15,468.21
	S3 / 2022	10		155,068.83	15,506.88
4	S4 / 2011	10	606,719.79	261,517.15	26,151.72
	S4 / 2012	10		266,747.49	26,674.75
	S4 / 2013	10		270,748.71	27,074.87
	S4 / 2014	10		273,131.29	27,313.13
	S4 / 2015	10		274,087.25	27,408.73
	S4 / 2016	10		282,995.09	28,299.51
	S4 / 2017	10		283,702.58	28,370.26
	S4 / 2018	10		284,411.83	28,441.18
	S4 / 2019	10		285,122.86	28,512.29
	S4 / 2020	10		285,835.67	28,583.57
	S4 / 2021	10		286,550.26	28,655.03
	S4 / 2022	10		287,266.64	28,726.66
5	S5 / 2012	10	457,630.00	198,969.57	19,896.96
	S5 / 2013	10		201,954.11	20,195.41
	S5 / 2014	10		203,731.30	20,373.13
	S5 / 2015	10		204,444.36	20,444.44
	S5 / 2016	10		205,057.70	20,505.77
	S5 / 2017	10		205,570.34	20,557.03
	S5 / 2018	10		206,084.27	20,608.43

Number	DWTP Code/Year	Flow (L/sec)	CAPEX (TL)	CAPEX (€)	CAPEX (€/(L/sec))
	S5 / 2019	10		206,599.48	20,659.95
	S5 / 2020	10		207,115.98	20,711.60
	S5 / 2021	10		207,633.77	20,763.38
	S5 / 2022	10		208,152.85	20,815.29
6	S6 / 2010	10	387,820.00	194,884.42	19,488.44
	S6 / 2011	10		196,833.27	19,683.33
	S6 / 2012	10		200,769.93	20,076.99
	S6 / 2013	10		203,781.48	20,378.15
	S6 / 2014	10		205,574.76	20,557.48
	S6 / 2015	10		206,294.27	20,629.43
	S6 / 2016	10		206,913.15	20,691.32
	S6 / 2017	10		207,430.44	20,743.04
	S6 / 2018	10		207,949.01	20,794.90
	S6 / 2019	10		208,468.88	20,846.89
	S6 / 2020	10		208,990.06	20,899.01
	S6 / 2021	10		209,512.53	20,951.25
	S6 / 2022	10		210,036.31	21,003.63
7	S7 / 2010	10	351,000.00	176,381.91	17,638.19
	S7 / 2011	10		178,145.73	17,814.57
	S7 / 2012	10		181,708.64	18,170.86
	S7 / 2013	10		184,434.27	18,443.43
	S7 / 2014	10		186,057.29	18,605.73
	S7 / 2015	10		186,708.49	18,670.85
	S7 / 2016	10		187,268.62	18,726.86
	S7 / 2017	10		187,736.79	18,773.68
	S7 / 2018	10		188,206.13	18,820.61
	S7 / 2019	10		188,676.65	18,867.66
	S7 / 2020	10		189,148.34	18,914.83
	S7 / 2021	10		189,621.21	18,962.12
	S7 / 2022	10		190,095.26	19,009.53
8	S8 / 2020	11	2,043,000.00	254,420.92	23,129.17
	S8 / 2021	11		255,056.97	23,187.00
	S8 / 2022	11		255,694.62	23,244.97
9	S9 / 2011	12	479,606.00	206,726.72	17,227.23
	S9 / 2012	12		210,861.26	17,571.77
	S9 / 2013	12		214,024.18	17,835.35
	S9 / 2014	12		215,907.59	17,992.30
	S9 / 2015	12		216,663.27	18,055.27
	S9 / 2016	12		217,313.26	18,109.44
	S9 / 2017	12		217,856.54	18,154.71
	S9 / 2018	12		218,401.18	18,200.10
	S9 / 2019	12		218,947.18	18,245.60
	S9 / 2020	12		219,494.50	18,291.21
	S9 / 2021	12		220,043.29	18,336.94
	S9 / 2022	12		220,593.40	18,382.78
10	S10 / 2018	12	1,060,000.00	187,279.15	15,606.60

Number	DWTP Code/Year	Flow (L/sec)	CAPEX (TL)	CAPEX (€)	CAPEX (€/(L/sec))
	S10 / 2019	12		187,747.35	15,645.61
	S10 / 2020	12		188,216.72	15,684.73
	S10 / 2021	12		188,687.26	15,723.94
	S10 / 2022	12		189,158.98	15,763.25
11	S11 / 2017	12	783,000.00	190,048.54	15,837.38
	S11 / 2018	12		190,523.67	15,876.97
	S11 / 2019	12		190,999.97	15,916.66
	S11 / 2020	12		191,477.47	15,956.46
	S11 / 2021	12		191,956.17	15,996.35
	S11 / 2022	12		192,436.06	16,036.34
12	S12 / 2010	12	310,500.00	156,030.15	13,002.51
	S12 / 2011	12		157,590.45	13,132.54
	S12 / 2012	12		160,742.26	13,395.19
	S12 / 2013	12		163,153.40	13,596.12
	S12 / 2014	12		164,589.15	13,715.76
	S12 2015	12		165,165.21	13,763.77
	S12 2016	12		165,660.70	13,805.06
	S12 / 2017	12		166,074.85	13,839.57
	S12 / 2018	12		166,490.04	13,874.17
	S12 / 2019	12		166,906.27	13,908.86
	S12 / 2020	12		167,323.53	13,943.63
	S12 / 2021	12		167,741.84	13,978.49
	S12 / 2022	12		168,161.20	14,013.43
13	S13 / 2017	14	942,500.00	228,762.14	16,340.15
	S13 / 2018	14		229,334.04	16,381.00
	S13 / 2019	14		229,907.38	16,421.96
	S13 / 2020	14		230,482.14	16,463.01
	S13 / 2021	14		231,058.35	16,504.17
	S13 / 2022	14		231,636.00	16,545.43
14	S14 / 2018	15	1,080,900.00	190,971.73	12,731.45
	S14 / 2019	15		191,449.16	12,763.28
	S14 / 2020	15		191,927.78	12,795.19
	S14 / 2021	15		192,407.60	12,827.17
	S14 / 2022	15		192,888.62	12,859.24
15	S15 / 2011	15	400,000.00	172,413.79	11,494.25
	S15 / 2012	15		175,862.07	11,724.14
	S15 / 2013	15		178,500.00	11,900.00
	S15 / 2014	15		180,070.80	12,004.72
	S15 / 2015	15		180,701.05	12,046.74
	S15 / 2016	15		181,243.15	12,082.88
	S15 / 2017	15		181,696.26	12,113.08
	S15 / 2018	15		182,150.50	12,143.37
	S15 / 2019	15		182,605.88	12,173.73
	S15 / 2020	15		183,062.39	12,204.16
	S15 / 2021	15		183,520.05	12,234.67
	S15 / 2022	15		183,978.85	12,265.26

Number	DWTP Code/Year	Flow (L/sec)	CAPEX (TL)	CAPEX (€)	CAPEX (€/(L/sec))
16	S16 / 2015	18	954,500.00	316,059.60	17,558.87
	S16 / 2016	18		317,007.78	17,611.54
	S16 / 2017	18		317,800.30	17,655.57
	S16 / 2018	18		318,594.80	17,699.71
	S16 / 2019	18		319,391.29	17,743.96
	S16 / 2020	18		320,189.77	17,788.32
	S16 / 2021	18		320,990.24	17,832.79
	S16 / 2022	18		321,792.72	17,877.37
17	S17 / 2011	18	740,587.27	319,218.65	17,734.37
	S17 / 2012	18		325,603.02	18,089.06
	S17 / 2013	18		330,487.07	18,360.39
	S17 / 2014	18		333,395.36	18,521.96
	S17 / 2015	18		334,562.24	18,586.79
	S17 / 2016	18		335,565.93	18,642.55
	S17 / 2017	18		336,404.84	18,689.16
	S17 / 2018	18		337,245.85	18,735.88
	S17 / 2019	18		338,088.97	18,782.72
	S17 / 2020	18		338,934.19	18,829.68
	S17 / 2021	18		339,781.53	18,876.75
	S17 / 2022	18		340,630.98	18,923.94
18	S18 / 2013	18	767,016.00	303,168.38	16,842.69
	S18 / 2014	18		305,836.26	16,990.90
	S18 / 2015	18		306,906.69	17,050.37
	S18 / 2016	18		307,827.41	17,101.52
	S18 / 2017	18		308,596.98	17,144.28
	S18 / 2018	18		309,368.47	17,187.14
	S18 / 2019	18		310,141.89	17,230.11
	S18 / 2020	18		310,917.25	17,273.18
	S18 / 2021	18		311,694.54	17,316.36
	S18 / 2022	18		312,473.77	17,359.65
19	S19 / 2020	19	3,362,500.00	418,742.22	22,039.06
	S19 / 2021	19		419,789.07	22,094.16
	S19 / 2022	19		420,838.54	22,149.40
20	S20 / 2013	20	817,448,00	323,101.98	16,155.10
	S20 / 2014	20		325,945.27	16,297.26
	S20 / 2015	20		327,086.08	16,354.30
	S20 / 2016	20		328,067.34	16,403.37
	S20 / 2017	20		328,887.51	16,444.38
	S20 / 2018	20		329,709.73	16,485.49
	S20 / 2019	20		330,534.00	16,526.70
	S20 / 2020	20		331,360.34	16,568.02
	S20 / 2021	20		332,188,74	16,609.44
	S20 / 2022	20		333,019,21	16,650.96
21	S21 / 2010	21	810, 000.00	407,035.18	19,382.63
	S21 / 2011	21		411,105.53	19,576.45
	S21 / 2012	21		419,327.64	19,967.98

Number	DWTP Code/Year	Flow (L/sec)	CAPEX (TL)	CAPEX (€)	CAPEX (€/(L/sec))
	S21 / 2013	21		425,617.55	20,267.50
	S21 / 2014	21		429,362.99	20,445.86
	S21 / 2015	21		430,865.76	20,517.42
	S21 / 2016	21		432,158.35	20,578.97
	S21 / 2017	21		433,238.75	20,630.42
	S21 / 2018	21		434,321.85	20,681.99
	S21 / 2019	21		435,407.65	20,733.70
	S21 / 2020	21		436,496.17	20,785.53
	S21 / 2021	21		437,587.41	20,837.50
	S21 / 2022	21		438,681.38	20,889.59
22	S22 / 2020	22	3,780,558.23	470,804.26	21,400.19
	S22 / 2021	22		471,981.27	21,453.69
	S22 / 2022	22		473,161.23	21,507.33
23	S23 / 2021	22	5,167,000.00	493,505.25	22,432.06
	S23 / 2022	22		494,739.02	22,488.14
24	S24 / 2021	23	4,985,770.00	476,195.80	20,704.17
	S24 / 2022	23		477,386.29	20,755.93
25	S25 / 2009	25	1,232,000.00	573,023.26	22,920.93
	S25 / 2010	25		586,661.21	23,466.45
	S25 / 2011	25		592,527.82	23,701.11
	S25 / 2012	25		604,378.38	24,175.14
	S25 / 2013	25		613,444.05	24,537.76
	S25 / 2014	25		618,842.36	24,753.69
	S25 / 2015	25		621,008.31	24,840.33
	S25 / 2016	25		622,871.33	24,914.85
	S25 / 2017	25		624,428.51	24,977.14
	S25 / 2018	25		625,989.58	25,039.58
	S25 / 2019	25		627,554.56	25,102.18
	S25 / 2020	25		629,123.44	25,164.94
	S25 / 2021	25		630,696.25	25,227.85
	S25 / 2022	25		632,272.99	25,290.92

D. Adjusted CAPEX for Large-Capacity DWTPs

Table D 1 CAPEX for the year of construction and adjusted to 2022 for large capacity DWTPs

Number	DWTP Code/Year	Flow (L/sec)	CAPEX (TL)	CAPEX (€)	CAPEX (€/m^3)
1	L1 / 2015	30	708,000.00	234,437.09	7,814.57
	L1 / 2016	30		235,140.40	7,838.01
	L1 / 2017	30		235,728.25	7,857.61
	L1 / 2018	30		236,317.57	7,877.25
	L1 / 2019	30		236,908.36	7,896.95
	L1 / 2020	30		237,500.63	7,916.69
	L1 / 2021	30		238,094.39	7,936.48
	L1 / 2022	30		238,689.62	7,956.32
2	L2 / 2010	30	546,294.84	274,520.02	9,150.67
	L2 / 2011	30		277,265.22	9,242.17
	L2 / 2012	30		282,810.52	9,427.02
	L2 / 2013	30		287,052.68	9,568.42
	L2 / 2014	30		289,578.75	9,652.62
	L2 / 2015	30		290,592.27	9,686.41
	L2 / 2016	30		291,464.05	9,715.47
	L2 / 2017	30		292,192.71	9,739.76
	L2 / 2018	30		292,923.19	9,764.11
	L2 / 2019	30		293,655.50	9,788.52
	L2 / 2020	30		294,389.64	9,812.99
	L2 / 2021	30		295,125.61	9,837.52
	L2 / 2022	30		295,863.43	9,862.11
3	L3 / 2018	33	1,248.000.00	220,494.70	6,681.66
	L3 / 2019	33		221,045.94	6,698.36
	L3 / 2020	33		221,598.55	6,715.11
	L3 / 2021	33		222,152.55	6,731.90
	L3 / 2022	33		222,707.93	6,748.73
4	L4 / 2016	33	780,110.75	233,566.09	7,077.76
	L4 / 2017	33		234,150.01	7,095.45

Number	DWTP Code/Year	Flow (L/sec)	CAPEX (TL)	CAPEX (€)	CAPEX (€/m^3)
	L4 / 2018	33		234,735.38	7,113.19
	L4 / 2019	33		235,322.22	7,130.98
	L4 / 2020	33		235,910.53	7,148.80
	L4 / 2021	33		236,500.30	7,166.68
	L4 / 2022	33		237,091.55	7,184.59
5	L5 / 2018	36	976,000.00	172,438.16	4,789.95
	L5 / 2019	36		172,869.26	4,981.55
	L5 / 2020	36		173,301.43	5,224.65
	L5 / 2021	36		173,734.68	5,444.60
	L5 / 2022	36		174,169.02	5,574.19
6	L6 / 2014	40	941,000.00	323,367.70	8,084.19
	L6 / 2015	40		324,499.48	8,112.49
	L6 / 2016	40		325,472.98	8,136.82
	L6 / 2017	40		326,286.67	8,157.17
	L6 / 2018	40		327,102.38	8,177.56
	L6 / 2019	40		327,920.14	8,198.00
	L6 / 2020	40		328,739.94	8,218.50
	L6 / 2021	40		329,561.79	8,239.04
	L6 / 2022	40		330,385.69	8,259.64
7	L7 / 2015	42	907,000.00	300,331.13	7,150.74
	L7 / 2016	42		301,232.12	7,172.19
	L7 / 2017	42		301,985.20	7,190.12
	L7 / 2018	42		302,740.16	7,208.10
	L7 / 2019	42		303,497.01	7,226.12
	L7 / 2020	42		304,255.76	7,244.18
	L7 / 2021	42		305,016.39	7,262.30
	L7 / 2022	42		305,778.94	7,280.45
8	L8 / 2018	49	1,807,000.00	319,257.95	6,515.47
	L8 / 2019	49		320,056.10	6,531.76
	L8 / 2020	49		320,856.24	6,548.09
	L8 / 2021	49		321,658.38	6,564.46
	L8 / 2022	49		322,462.52	6,580.87
9	L9 / 2020	50	3,967, 545.00	494,090.29	9,881.81
	L9 / 2021	50		495,325.51	9,906.51

Number	DWTP Code/Year	Flow (L/sec)	CAPEX (TL)	CAPEX (€)	CAPEX (€/m^3)
	L9 / 2022	50		496,563.83	9,931.28
10	L10 / 2011	50	935,759.90	403,344.78	8,066.90
	L10 / 2012	50		411,411.68	8,228.23
	L10 / 2013	50		417,582.86	8,351.66
	L10 / 2014	50		421,257.58	8,425.15
	L10 / 2015	50		422,731.99	8,454.64
	L10 / 2016	50		424,000.18	8,480.00
	L10 / 2017	50		425,060.18	8,501.20
	L10 / 2018	50		426,122.83	8,522.46
	L10 / 2019	50		427,188.14	8,543.76
	L10 / 2020	50		428,256.11	8,565.12
	L10 / 2021	50		429,326.75	8,586.54
	L10 / 2022	50		430,400.07	8,608.00
11	L11 / 2017	52	1,510,000.00	366,504.85	7,048.17
	L11 / 2018	52		367,421.12	7,065.79
	L11 / 2019	52		368,339.67	7,083.46
	L11 / 2020	52		369,260.52	7,101.16
	L11 / 2021	52		370,183.67	7,118.92
	L11 / 2022	52		371,109.13	7,136.71
12	L12 / 2013	54	1,106,250.00	437,252.96	8,097.28
	L12 / 2014	54		441,100.79	8,168.53
	L12 / 2015	54		442,644.64	8,197.12
	L12 / 2016	54		443,972.58	8,221.71
	L12 / 2017	54		445,082.51	8,242.27
	L12 / 2018	54		446,195.21	8,262.87
	L12 / 2019	54		447,310.70	8,283.53
	L12 / 2020	54		448,428.98	8,304.24
	L12 / 2021	54		449,550.05	8,325.00
	L12 / 2022	54		450,673.93	8,345.81
13	L13 / 2020	70	6,902,000.00	859,526.77	12,278.95
	L13 / 2021	70		861,675.59	12,309.65
	L13 / 2022	70		863,829.78	12,340.43
14	L14 / 2022	70		781,127.45	11,158.96
15	L15 / 2020	100	8,814,031.00	1,097,637.73	10,976.38

Number	DWTP Code/Year	Flow (L/sec)	CAPEX (TL)	CAPEX (€)	CAPEX (€/m^3)
	L15 / 2021	100		1,100,381.83	11,003.82
	L15 / 2022	100		1,103,132.78	11,031.33
16	L16 / 2015	100	3,828,000.00	1,267,549.67	12,675.50
	L16 / 2016	100		1,271,352.32	12,713.52
	L16 / 2017	100		1,274,530.70	12,745.31
	L16 / 2018	100		1,277,717.03	12,777.17
	L16 / 2019	100		1,280,911.32	12,809.11
	L16 / 2020	100		1,284,113.60	12,841.14
	L16 / 2021	100		1,287,323.88	12,873.24
	L16 / 2022	100		1,213,000.00	12,905.42
17	L17 / 2021	100	13,233,022.29	1,263,898.98	12,638.99
	L17 / 2022	100		1,267,058.72	12,670.59

E. OPEX of Small-Capacity DWTPs

Table E 1 OPEX and unit water costs of small capacity DWTPs in 2022

Name	Flow (L/sec)	OPEX/ 2022 (€)	Unit Water Cost (€/(m^3/Year))
S1	7	58,702.43	0.27
S2	7	57,252.54	0.26
S3	10	57,891.17	0.18
S4	10	61,793.60	0.20
S5	10	62,843.97	0.20
S6	10	66,346.93	0.21
S7	10	65,578.91	0.21
S8	11	67,390.73	0.19
S9	12	68,231.46	0.18
S10	12	70,196.46	0.19
S11	12	72,282.77	0.19
S12	12	71,854.64	0.19
S13	14	76,449.88	0.17
S14	15	78,261.73	0.17
S15	15	77,010.18	0.16
S16	18	79,837.08	0.14
S17	18	77,623.99	0.14
S18	18	79,022.13	0.14
S19	19	83,929.86	0.14
S20	20	87,333.51	0.14
S21	21	98,413.07	0.15
S22	22	102,030.86	0.15
S23	22	103,779.39	0.15
S24	23	106,510.47	0.15
S25	25	115,592.66	0.15

F. OPEX of Large-Capacity DWTPs

Table F. 1 OPEX and unit water costs of large capacity DWTPs in 2022

Name	Flow (L/sec)	OPEX/2022 (€)	Unit Water Cost (€/(Year/m^3))
L1	30	100,031.53	0.11
L2	30	104,386.30	0.11
L3	33	106,463.83	0.10
L4	33	106,604.45	0.10
L5	36	113,517.21	0.10
L6	40	121,631.71	0.10
L7	42	128,140.62	0.10
L8	49	139,560.53	0.09
L9	50	153,709.87	0.10
L10	50	149,684.42	0.09
L11	52	161,592.61	0.10
L12	54	169,552.84	0.10
L13	70	198,737.26	0.09
L14	70	197,722.09	0.09
L15	100	243,882.62	0.08
L16	100	244,304.41	0.08
L17	100	250,774.43	0.08

G. Laboratory Materials

Table G 1 General laboratory materials of the DWTPs

Name	Piece
Etuv	1
Portable pH Conductivity Oxygen Meter	1
Spectrophotometer	1
Turbidity meter	1
Analytic Libra	1
Chlorine Measuring Device	1
Pure Water Device	1
Magnetic Mixer With Heater	1
Flocculator	1
Refrigerator	1
Analysis Kits	Different Pieces
Various Glassware and Other Materials (Straw, Tape Measure, Beaker, Etc.)	Different Pieces
Chemical Materials (Vaseline, Sulfuric Acid Ethyl Alcohol, Etc.)	Different Pieces

H. Raw Water Quality for Selected DWTPs

Parameters	Regulation on the quality and treatment of drinking water supplied.				Selected sample plant parameters			
	Unit	A1	A2	A3	S1 (7 L/s)	S10 (12 L/s)	L5 (36 L/s)	L10 (50 L/s)
1,1 dichloretan	µg/L	140	-	700	<0.1	<0.1	<0.1	<0.1
1,2 dichloretan	µg/L	3	-	15	<0.1	<0.1	<0.1	<0.1
2,4-d isooctyl ester	µg/L	0.10	0.14	0.25	<0.01	<0.01	<0.1	<0.1
22 ^{0}C Colony count	/mL	20			0	0	0	0
4-chloranilin	µg/L	0.10	-	0.33	<0.01	<0.01	<0.01	<0.1
Akrilamid	µg/L	0.10	-	0.30	<0.1	<0.05	<0.1	<0.05
Alaclor	µg/L	0.10	0.13	0.50	<0.05	<0.05	<0.05	<0.05
Aldrin	µg/L	0.03	0.03	0.10	<0.01	<0.01	<0.01	<0.01
Aluminum	µg/L	200	500	2000	24	21.9	<20	<20
Ammonium	mg/L	0.50	2.50	5.00	<0.021	<0.02	0.052	0.071
Anatoxin	µg/L	3.00	-	15.00	<0.1	<0.1	<0.1	<0.1
Antimon	µg/L	4	15	50	<1	<1	<0.5	0.61
Arsenic	µg/L	10	40	100	<0.01	<0.01	2.23	<0.01
Acetochlor	µg/L	0.10	0.11	0.25	<0.05	<0.05	<0.05	<0.05
Copper	µg/L	2000	5000	20000	<1	<1	<1	<1
Barium	µg/L	2000	-	20000	1	1	171	171
Benzene	µg/L	1	-	3	<0.1	<0.1	<0.1	<0.1
Beryllium	µg/L	60	300	600	<1	<1	<0.5	<0.5
Boron	µg/L	1000	1250	5000	<100	<100	22	<100
Bromate	µg/L	10	12	100	<5	<0.1	<0.1	<0.1
Bromoxynyl	µg/L	0.10	-	0.20	<0.05	<0.05	<0.05	<0.05
Bromide	µg/L	2000	4000	65000	<25	<25	<25	<25
Turbidity	NTU	1	50	500	0.64	0.74	0.104	0.75
C. Perfingens					0	0	0	0
Zinc	µg/L	3000	6000	12000	<1	<1	<1	<1
Mercury	µg/L	1	3	5	<0.2	<0.1	<0.1	<0.1
Cryptosporidium Ooksit	/L	0.075	-	1.00	0	0	0	0
Iron	µg/L	200	1000	2000	21	6.3	210.68	<100
Di Fitalate	µg/L	10	15	35	<1	<1	<1	<1
Dieldrin	µg/L	0.03	0.04	0.15	<0.017	<0.01	<0.01	<0.01
Dichloromethane	µg/L	20	-	100	<0.01	<0.01	<0.01	<0.01
Dichlorvos	µg/L	0.10	0.12	0.15	<0.005	<0.005	<0.005	<0.005
Diclobenyl	µg/L	0.10	-	0.25	<0.005	<0.005	<0.005	<0.005
Dichloracetic Acid	µg/L	0.10	-	0.50	<0.01	0.03	<0.01	<0.01

Parameters	Regulation on the quality and treatment of drinking water supplied.				Selected sample plant parameters			
	Unit	A1	A2	A3	S1 (7 L/s)	S10 (12 L/s)	L5 (36 L/s)	L10 (50 L/s)
Dicofol	µg/L	0.10	0.50	0.65	<0.005	<0.03	<0.005	<0.005
Diuron	µg/L	0.10	0.30	1.00	<0.05	<0.05	<0.05	<0.05
E.Coli	/100 mL	0			0	0	0	0
ETU	µg/L	0.10	0.25	0.50	<0.05	<0.005	<0.005	<0.005
Fecal Coliform	/250 mL	0			2.00	21.30	<1.8	<1.8
Fecal Steptpcoc.	/250 mL	0			1.00	2.00	<1.8	2.50
Phenols	mg/L	0.002	0.005	0.01	0.0001	0.0001	<0.001	<0.001
Fention	µg/L	0.10	-	0.50	<0.05	<0.05	<0.05	<0.05
Fluoride	µg/L	1500	5000	7500	<0.2	<0.2	<0.2	<0.2
Hexachloro-benzene	µg/L	0.10	-	0.50	<0.01	<0.01	<0.01	<0.01
Hexachloro-cyclohexene	µg/L	0.10	-	0.50	<0.01	<0.04	<0.04	<0.04
Heptachlor	µg/L	0.03	0.06	0.10	<0.01	<0.01	<0.01	<0.01
Heptachlor epoxide	µg/L	0.03	0.045	0.15	<0.01	<0.01	<0.01	<0.01
Conductivity (20ºC)	µS/cm	2500	-	25000	29	24	741	1708
Cadmium	µg/L	5	15	50	<1	<0.1	<0.1	<0.1
Captan	µg/L	0.10	-	0.50	<0.005	<0.005	<0.005	<0.005
Carbendazime	µg/L	0.10	-	0.20	<0.05	<0.05	<0.05	<0.05
Chloracetic acid	µg/L	0.10	-	0.50	<0.1	<0.03	<0.05	<0.05
Chlordan	µg/L	0.10	0.13	0.50	<0.01	<0.02	<0.02	<0.02
Chlorothalonyl	µg/L	0.10	0.30	0.50	<0.005	<0.05	<0.05	<0.05
Chlorpyriphos	µg/L	0.10	0.15	0.50	<0.05	<0.05	<0.05	<0.05
Chloride	mg/L	250	-	1250	0.3	0.6	0.6	248.79
Cobalt	µg/L	800	-	2600	<1	<1	<0.5	<1
Odor	TKEDY				Normal	Norm.	Normal	Normal
Chrome	µg/L	50	500	5000	<1	<1	<1	<1
Lead	µg/L	10	50	100	<1	<1	<0.5	<0.5
Linuron	µg/L	0.10	-	0.25	<0.05	<0.05	<0.05	<0.05
Manganese	µg/L	50	100	250	5.8	2.3	0.004	32
Metolachlor	µg/L	0.10	0.11	0.30	<0.05	<0.05	<0.05	<0.05
Microcystin-LR	µg/L	1.00	-	5.00	<1	<0.3	<0.3	<0.3
Naphthalene	µg/L	100	120	500	<0.005	<0.005	<0.005	<0.005
Nickel	µg/L	20	30	200	<1	<1	<5	<5
Nitrate	mg/L	50	-	330	0.7	1.9	1.95	3.52

Parameters	Regulation on the quality and treatment of drinking water supplied.				Selected sample plant parameters			
	Unit	A1	A2	A3	S1 (7 L/s)	S10 (12 L/s)	L5 (36 L/s)	L10 (50 L/s)
Nitrite	mg/L	0.50	-	3.33	<0.1	<0.32	<0.92	<0.32
Oxidisability	mg/L	5			<5	<5	<5	0.3
Octobromodiphenyl ether	µg/L	9.00	13.00	39.00	<0.01	<0.01	<0.001	<0.001
Orthophosphate	mg/L	0.40	0.70	-	<0.15	<0.15	<0.15	<0.15
P. Aeruginosa	/250 mL	0			0	0	0	0
Paraquat	µg/L	0.10	-	0.33	<0.05	<0.05	<0.05	<0.05
Paration	µg/L	0.10	0.50	2.00	<0.005	<0.05	<0.05	<0.05
Parathion methyl	µg/L	0.10	0.50	2.00	<0.005	<0.05	<0.05	<0.05
Pathogenic Microorganisms	/100 mL	0			0	0	0	0
Pathogenic Staphylcocs	/100 mL	0			0	0	0	0
Pebulate	µg/L	0.10	-	-	<0.05	<0.05	<0.05	<0.05
Pendimethalin	µg/L	0.10	-	0.25	<0.05	<0.08	<0.05	<0.08
Pentachlorophenol	µg/L	0.10	-	0.30	<0.001	<0.08	<0.001	<0.08
Pentachlorobenzene	µg/L	3.00	6.00	10.00	<0.001	<0.001	<0.001	<0.001
Permetrin	µg/L	0.10		0.50	<0.05	<0.05	<0.05	<0.05
pH	-	>6.5 and <9.5			7.85	6.55	7.30	7.78
Polychlorinated Biphenyls	µg/L	0.05	-	0.15	<0.01	<0.01	<0.001	<0.01
Color	Pt-Co	f	30	150	13	14.2	<5	
Saxitoxin	µg/L	1.00	-	5.00	<1	<0.3	<0.3	<0.3
Selenium	µg/L	10	20	100	<1	<1	<0.5	8.12
Silindrospermopsin	µg/L	1.00	-	5.00	<1	<0.3	<1	<0.2
Cypermethrin	µg/L	0.10	-	1.00	<0.01	<0.04	<0.04	<0.04
Cyanide	µg/L	50.00	-	125	<1	<1	<5	<5
Sodium	mg/L	200			<100	<100	36.5	184
Sulfate	mg/L	250.00	-	1250	0.9	1.5	68.2	212.64
Taste		TKEDY			Normal	Norm.	Normal	Normal
Terbutrin	µg/L	0.10	0.20	0.50	<0.05	<0.05	<0.05	<0.05
Tetrachlorothene and trichlorothene	µg/L	10			0	0	0	0
Tetrachloroethylene	µg/L	10	10	100	<0.01	1.2	1.2	1.2
Total DDT	µg/L	0.10	0.25	0.50	<0.01	<0.02	<0.01	<0.02
Total Koliform	EMS /100 ml	50	5000	50000	80.50	410.60	<1.80	3

Parameters	Regulation on the quality and treatment of drinking water supplied.				Selected sample plant parameters			
	Unit	A1	A2	A3	S1 (7 L/s)	S10 (12 L/s)	L5 (36 L/s)	L10 (50 L/s)
TOC	mg/L	4.00	4.70	10.00	1.3	1.6	<4	1.5
Total Pesticide	µg/L	0.5			<0.0005	<0.001	<0.0005	<0.001
Total Hardness	mg/L	61	-	120	65	65	78	80
Tribuneron methyl	µg/L	0.10	0.11	0.25	<0.05	<0.05	<0.05	<0.05
Trifluralin	µg/L	0.10	0.50	1.00	<0.005	<0.005	<0.005	<0.005
Trihalomethanes	-	-	-	-	<1	<1	<1	<1
Trichlorethylene	µg/L	10.00	20.00	50.00	<0.1	<0.1	<0.1	<0.1
Trichlorpacetic acid	µg/L	0.10	-	0.50	<0.005	<0.03	<0.005	<0.03
Trichlosane	µg/L	0.30	-	0.80	<0.0005	<0.001	<0.0005	<0.001
Vanadium	µg/L	15	50	150	<1	<1	<1	<1
Vinyl chloride	µg/L	0.5			<0.1	<0.1	<0.1	0