DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

ASSESSMENT OF SUSTAINABLE SLUDGE MANAGEMENT OPTIONS FOR ANTALYA

by
Elif KILAVUZ TURAN

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İZMİR

ASSESSMENT OF SUSTAINABLE SLUDGE MANAGEMENT OPTIONS FOR ANTALYA

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"ASSESSMENT OF SUSTAINABLE SLUDGE MANAGEMENT OPTIONS FOR ANTALYA"** completed by **ELİF KILAVUZ TURAN** under supervision of **PROF.DR. NURDAN BÜYÜKKAMACI** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ASSESSMENT OF SUSTAINABLE SLUDGE MANAGEMENT OPTIONS FOR ANTALYA

ABSTRACT

One of the most important issues in the operation of the wastewater treatment plant is the management of sludge. In Turkey, domestic/municipal wastewater treatment plants; in 2014, approximately 620,000 tones dry matter of sludge was produced and this amount is expected to be about 895,000 tones dry matter of for 2023. Currently, the most suitable solutions for the management of sewage sludge are being investigated and many projects are being carried out about this subject.

In this thesis, it is aimed to make suggestions for the management of domestic and industrial sludges produced in Antalya. For this purpose, based on the year 2017, some information compiled about the amount of existing sewage sludge, the sludge disposal methods and the problems encountered. The most important reason for the sludge problem in Antalya is, the varying wastewater flow rates cause of tourist population and the amount of sludge produced as a result of this change during the year. This situation causes sludge production much higher than the expected sludge amount when the city population is taken into consideration and it makes management quite difficult.

In the first stage of the study, population projection was carried out to calculate the amount of sludge to be produced in 2037. The capacity increase is foreseen for industrial sludge, and the quantity estimate was made accordingly to this. Considering the locations and capacities of existing sludge disposal treatments (drying plant, incineration plant, landfilling, cement plants, etc.); various scenarios have been produced for the management of sludges. According to the scenarios, necessary investment costs and sludge transportation costs were calculated.

Keywords: Sludge, management, Antalya

ANTALYA İÇİN SÜRDÜRÜLEBİLİR ÇAMUR YÖNETİMİ SEÇENEKLERİNİN DEĞERLENDİRİLMESİ

ÖZ

Atıksu arıtma tesisi işletilmesinde en önemli konulardan biri arıtma çamurunun yönetimidir. Türkiye'de evsel/kentsel atıksu arıtma tesislerinde 2014 yılında yaklaşık 620.000 ton katı madde çamur oluşmuştur ve bu miktarın 2023 yılı için yaklaşık 895.000 ton katı madde olması beklenmektedir. Hali hazırda arıtma çamurlarının yönetimi için en uygun çözümler araştırılmakta ve bu konuya ilişkin pek çok proje yürütülmektedir.

Bu tez kapsamında, Antalya'da oluşan evsel ve endüstriyel arıtma çamurlarının yönetimi için öneriler getirilmesi hedeflenmiştir. Bu amaçla öncelikle, 2017 yılı baz alınarak, mevcut arıtma çamuru miktarı, arıtma çamuru bertaraf yöntemleri ve yaşanmakta olan problemlerle ilgili bilgiler derlenmiştir. Antalya'da yaşanan arıtma çamuru problemine ilişkin en önemli neden, şehre gelen turistler ile birlikte değişen atıksu debileri sonucu oluşan çamur miktarının yıl içinde farklılıklar göstermesidir. Bu durum şehir nüfusu göz önüne alındığında oluşması beklenen çamur miktarının kat ve kat üzerinde çamur oluşumuna neden olmakta ve yönetimi oldukça zorlaştırmaktadır.

Çalışmanın ilk aşamasında nüfus projeksiyonu yapılarak 2037 yılı için oluşacak evsel/kentsel arıtma çamuru miktarı hesap edilmiştir. Endüstriyel nitelikli arıtma çamurları miktarları için kapasite artışı öngörülerek miktar tahmini yapılmıştır. Mevcut arıtma çamuru bertaraf etme yerlerinin (kurutma tesisi, yakma tesisi, depolama tesisi, çimento fabrikaları, vb.) konumları ve kapasiteleri dikkate alınarak, arıtma çamurlarının yönetimi için çeşitli senaryolar üretilmiştir. Oluşturulan senaryolara göre gerekli yatırım maliyetleri ve arıtma çamuru taşıma maliyetleri hesaplanmıştır.

Anahtar Kelimeler:Arıtma çamuru, yönetim, Antalya

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CHAPTER ONE
INTRODUCTION

1.1 Introduction

The sludge management is one of the most significant challenges in wastewater management. Although the treatment of sludge is not as popular as long-term wastewater treatment in our country, it is among the priority issues for the environment. The amount of sludge formed in the municipal urban wastewater treatment plant in Turkey in 2014, 620,907.09 tons of dry matter and is calculated on an annual basis in 2023 is estimated to reach this amount of 895,581.92 tons of dry matter (RTMEU, 2016).

In wastewater treatment plants, the amount and properties of raw treatment sludge formed in pre-sedimentation, chemical sedimentation, and biological sedimentation tank vary according to the amount and properties of the treated wastewater. The amount and properties of treated sludge differ according to the sludge treatment methods as well as the characteristics of wastewater.

The processing, handling, and disposing of sludge are important cost items in a wastewater treatment plant. Treatment of sludge in plants; and its disposal is approximately half of the total wastewater treatment costs (Filibeli & Erden Kaynak, 2006; Seginer & Bux, 2006).

In the management of sewage sludge; approaches should be holistic, cost-effective alternatives should be selected, and public health and environmental safety elements should be integrated. Selection of sludge treatment systems; or at its final disposal; agricultural usage, incineration or storage alternatives should be considered as a whole. Sludge characteristics, country conditions, the country's economy, as well as the conditions specific to the region should be evaluated and elections should be made (Englande & Rimers, 2001).

Organic matter and heavy metal content of sewage sludge and planned soil are of great importance disposed of in soil, which is considered as the most economical option. Besides, it is one of the alternatives that are not implemented in Turkey within the scope of long-term discussions about the possibility of degradation of soil structure and its impacts on environment, human and plant health due to groundwater pollution.

The final disposal in order to obtain energy from sewage sludge with high organic matter content and calorific values is one of the options with increased popularity and implementation recently. However, the high initial investment cost and the difficulty in operating conditions and the cost are some of the disadvantages of final disposal for energy.

Another alternative is the storage in landfills, which is not a preferable option due to the high water content of sewage sludge covering a lot of space in the lots of these plants, and also because of the difficult operating conditions.

1.2 Aim and Scope of the Thesis

The purpose of the thesis is to evaluate the current status in the management of treatment sludge which is a problem in Antalya as in Turkey and which becomes more important considering the contribution of the city to the tourism revenues of the country. Also, the thesis aims and to determine all the stages that will contribute to the sludge management with a future projection. Within the scope of this thesis, scenarios have been developed by taking 2017 as a basis and 20 years population projection and different alternatives have been developed for the management of sludge to be formed in 2037, and investment cost for facilities along with the sludge transportation and disposal costs have been calculated and assessments were done accordingly.

In this study, determinations and general evaluation related to sewage sludge management problems in Antalya were carried out initially. Following this, general data (capacity, process, commissioning date, etc.) were collected regarding the existing wastewater treatment plants, population number for 2037 was calculated by using 20 years projection, sludge amounts formed by taking 2017 as a basis were arranged per treatment plant and the calculations of sludge amounts for 2017 and 2037 were done by considering the capacities of treatment plants and the processes implemented. As a result, three scenarios were formed related to sludge treatment for 2037 and investment, transportation and disposal costs were calculated.

CHAPTER TWO
SLUDGE MANAGEMENT ALTERNATIVES

Ensuring the proper management of the sludges formed in wastewater treatment plants is important in terms of environment and human health. As the management of sludge is not identified as a top priority in many treatment plants established to meet the increasing demand for treatment nowadays, and according to Turonskiy& Mathai (2006), although the sludge amount is approximately 1% of the amount of wastewater, the management costs are about 40-50% of the total cost of a wastewater treatment plant and therefore sludge management is a huge problem. The management of sludge, which has an increasing amount every year and the need to take measures for its management, has increasing importance in our country as well as in the world.

It is essential to reduce the water and organic matter contents as the sludges have high levels of water content. There should also be treated using appropriate processes for their recovery and disposal. The main purpose of the methods used for the processing and treatment of sludge is to reduce the moisture content in the thickening, conditioning, dewatering and drying methods. It is stabilized by reducing the organic content of the sludge by means of incineration, composting and stabilization. In addition to these methods, following the necessary analyses of dewatered treatment sludge; final disposal can be achieved by storing them in landfills in accordance with their characteristics (Communiqué on Technical Procedures for Wastewater Treatment Plants, 2010).

Among the most common methods applied in the past in the disposal of sludge, land application and solar drying in arid climate areas alternatives are prominent (The Scientific and Technological Research Council of Turkey [TÜBİTAK], 2013). Nowadays, although some of these methods are abandoned, it is essential to apply the processes for obtaining energy from the sludge high calorific value.

Some sludge management alternatives depending on the scale of a wastewater treatment plant are given in Figure 2.1-2.3.

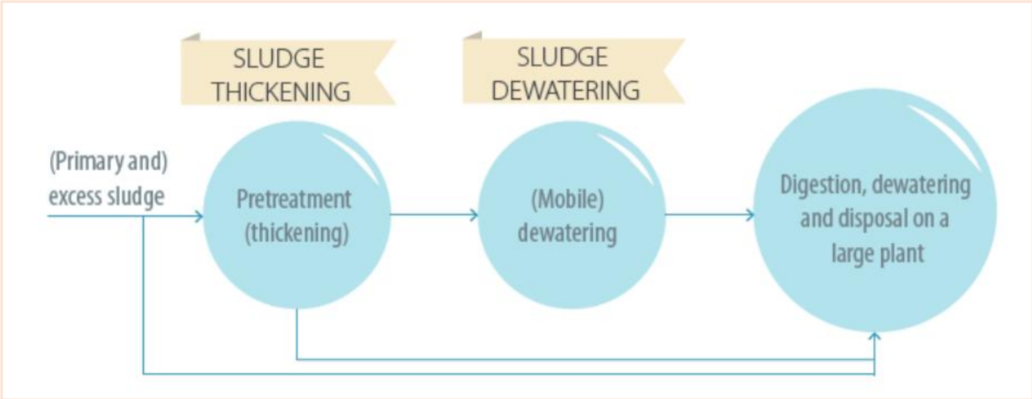

Figure 2.1 Typical sludge handling for medium-sized wastewater treatment plants (PURE, 2012)

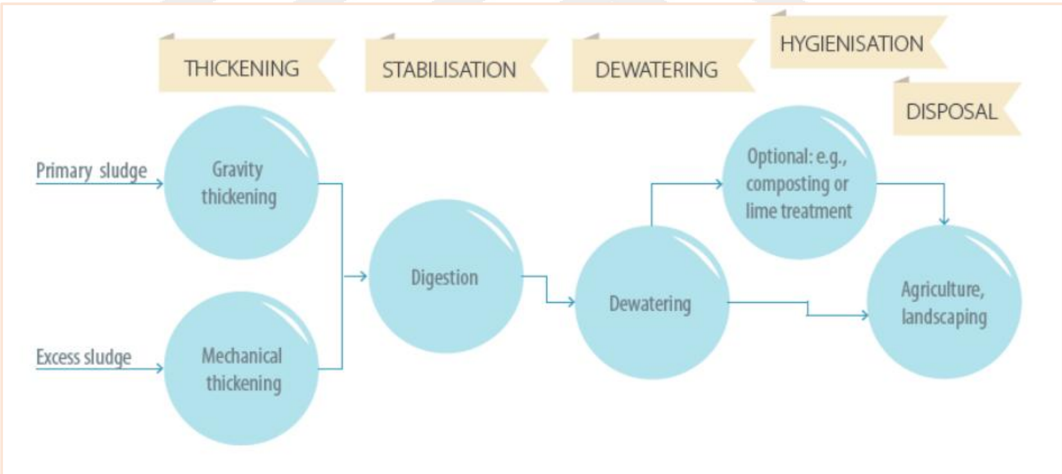

Figure 2.2 Typical sludge handling for medium-sized, large wastewater treatment plants (PURE, 2012)

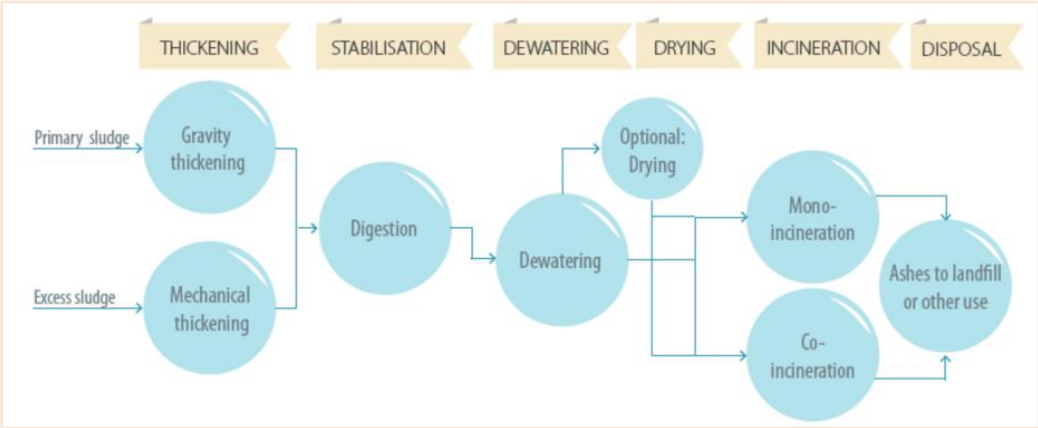

Figure 2.3 Typical sludge handling for large wastewater treatment plants (PURE, 2012)

Thickening, stabilization, and dewatering are the indispensable units in domestic wastewater treatment plants regarding sludge management. Additional methods, such as hygienisation, drying, or incineration may be applied before final disposal by taking into account the amount and characteristics of sludge formed in the treatment plant as a result of these stages. In addition, energy recovery alternatives that benefit from the calorific value of sludge are stages of management that are widespread recently.

2.1 Thickening

A first and most important step in the reduction of sludge volume is thickening. The conditioning, stabilization and dewatering stages follow this step as it reduces the size of structure and costs of operation.

There are several methods for thickening sludge, including gravity thickening, dissolved air floatation (DAF), centrifuge, gravity belt thickening, and rotary drum thickening (EPA, 2003). Thickening methods and expected performances depending on the total solids (TS) with various sludge types are given in Table 2.1.

Table 2.1 Thickening methods and performance (Ontario Ministry of Environment, 2008)

Thickening Method	**Sludge Type**	**Expected Performance**
Centrifugation	Waste Activated with Polymer	• Basket Centrifuges: 8-10% TS and 80-90% SolidsCapture • Disc-nozzle Centrifuges: 4-6% TS and 80-90% SolidsCapture • Solid Bowl Centrifuges: 5-8% TS and 70-90% SolidsCapture
Gravity Belt Thickener (GBT)	Waste Activated with Polymer	4-8% TS and 95% Solids Capture
Rotary Drum Thickener (RDT)	Waste Activated with Polymer	4-8% TS and 95% Solids Capture
Gravity	Raw Primary	8-10% TS
Gravity	Raw Primary and Waste Activated	5-8% TS
Gravity	Waste Activated	2-3% TS
Gravity	Digested Primary and Waste Activated	8-14% TS
Dissolved Air Flotation (DAF)	Waste Activated	4-6% TS and ≥ 95% Solids

2.1.1 Gravity Thickening

Another treatment process, which has been used first, is the gravity thickening. It is simple and it requires low energy, which makes it an ideal candidate to continue to be applied for solids and film processes (Dentel, 2001).

Sludge is directly pumped into a circular tank with a slowly rotating rake mechanism, which is used to break the junction among the sludge particles and increasing the settling and compaction. Other thickening methods have a better performance regarding waste activated sludge, gravity thickening is limited for those (PURE, 2012; OME, 2008).

2.1.2 Dissolved Air Flotation

Dissolved air flotation (DAF) is another system used for sludge thickening. Primary and waste activated sludges are mostly and effectively thickened in gravity thickeners; however, DAF can be used to thicken the light waste bioreactor sludges effectively. When we compare with gravity thickeners, DAF is more reliable with a higher amount of sludge concentration production and better capture of solids regarding the excess secondary treatment sludges. However, it needs a better operating skill and higher costs of operation (OME, 2008).

2.1.3 Centrifuge Thickening

Both for sludge dewatering and for sludge thickening centrifuges are commonly used. The centrifuge revolves fastly to separate the water and solids. The centrifuge used for thickening has been generally restricted to waste activated sludge. The solid-bowl decanter, disc-nozzle, and basket are types of the centrifuge. Centrifuges are fully enclosed to minimize odors and environmental impact. Thickening centrifuges can reach a dissolved solid content of about 5–7% (PURE, 2012; OME, 2008).

2.1.4 Gravity Belt Thickener

The gravity belt thickener is basically the same as to the gravity drainage part of a belt press and is equipped for giving 5-11% solids. Requirements of area are substantially less than those with gravity thickening. The process relies on effective conditioning with the polymer to isolate the free water from the solids. Regardless of the polymer and energy necessities, this is better than DAF. The capacity to give an increasingly concentrated sludge to ensuing adjustment by processing is important because of the expanded maintenance times that can be accomplished with fixed volume digestion (Dentel, 2001).

2.1.5 Rotary Drum Thickener

Rotary drum thickeners work similarly gravity belt thickeners. The sludge is fed into a porous drum screen where free water can discharge through the drum wall. Then the remaining solids have carried the length of the drum. Rotary drum thickeners are in need of polymers for flocculation that separates water from the sludge. Even a few technical data has been published to confirm this, rotary drum thickeners technologies are supposed to use comparatively low amounts of energy (Gable, 2014).

2.2 Stabilization

Primary and secondary sludges also have an elevated biological oxygen demand (BOD) from an activated sludge treatment facility and can be hard to dewater. Even sludge from a septic tank that has been bacterially decomposed for at least one year still has an elevated BOD. The word used to indicate the BOD reduction method is stabilization. The biological stabilization process can be carried out either under aerobic or anaerobic conditions (Chena et al., 2010).

Stabilization methods are applied in order to make raw sludge formed in wastewater treatment plants suitable for public health and reuse. The stabilization of sludges is aimed at odor removal, reducing pathogenic microorganisms and potential degradation (Kücükhemek & Berktay, 2005).

In spite of the fact that there are various ways of sludge management such as composting, sludge lagoons, lime stabilization, heat stabilization, irradiation, sludge drying beds, etc., stabilization is expectedly done by anaerobic stabilization in most of wastewater treatment plants (Apul, 2009).

2.2.1 Lime Stabilization

Lime may be put into primary and/or secondary sludge, for stabilization, to complete existing digestion facilities, or to handle the sludge temporary. The organic matter or solids are not degraded directly with the high pH alkaline stabilization process (OME, 2008).

Generally, alkaline stabilization has reduced the level of pathogen requirements when the pH of sludge and lime's mixture is at 12, or after contact over 2 hours. The pH of the mixture is kept above 12 for at least 72 hours and the temperature is kept an of 52°C for at least 12 hours during this time there is no need for any pathogen that can be obtained. In one period, after the 72-hour sludge and the lime mixture is kept with high pH, sludge is produced which has 50% of the dried solid content (EPA, 2000 a).

2.2.2 Anaerobic Stabilization

Anaerobic digestion is a common practice in sludge stabilization because both organic materials are converted to biogas (60 to 70% methane), which also reduces the final sludge amount to be disposed of and significantly reduces the number of pathogens present in the sludge. This situation limits the hazards related to sludge. Anaerobic digestion has some problems, such as operational problems, destruction of poor organic solids, poor disintegration of refractory materials causing to the production of low biogas, foaming due to the presence of filamentous microorganisms, and ultimately high polymer consumption to get high dry solid cake. (Appels, Dewil & Baeyens, 2008). Anaerobic digestion process in the sludge handling chain is shown in Figure 2.4.

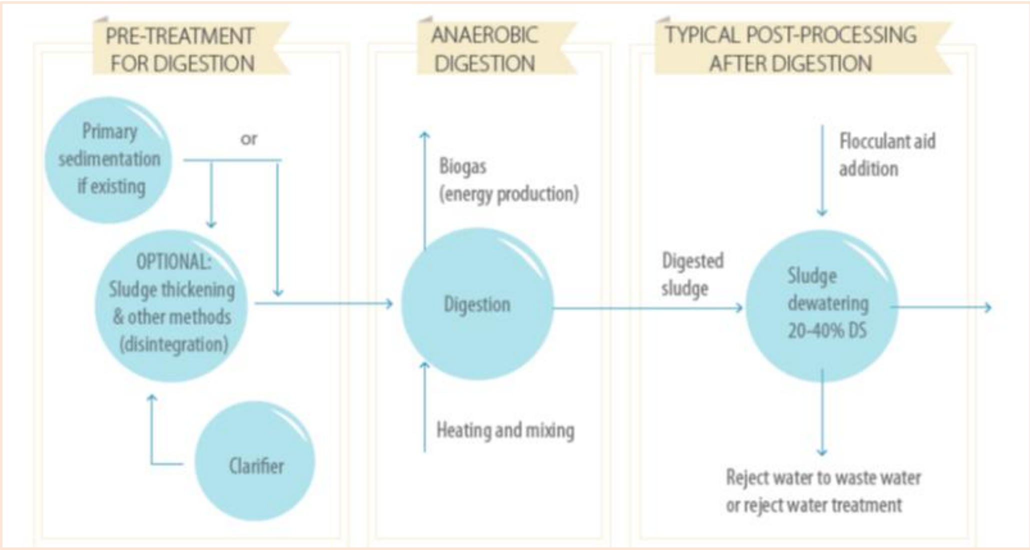

Figure 2.4 Anaerobic digestion process in the sludge handling chain (PURE, 2012)

Anaerobic digestion is carried out at mesophilic in temperature about 35-40°C or thermophilic in temperature about 53-57°C. Basically, there are two types of mesophilic digestion: dry and wet digestion. The mesophilic process is used commonly and the temperature is normally about 35-40°C range and the advantages are reliable processing experience with good process stability and supernatant quality. Mesophilic digestion occurs in one or more reactors which sludge may be fed in parallel or sequentially with a retention time of 20 to 25 days. The low retention time normally reduces gas production and the minimum retention time is about 14 to 15 days, but some plants operate with retention times of less than 14 days without any decrease in biogas production, as a result, the sludge is biodegradable (PURE, 2012).

Thermophilic digestion occurs at temperatures from 50 to 57°C range. The biochemical reaction value doubles with every 10°C increase in temperature until reaching the limiting temperature. Thermophilic digestion occurs much faster than mesophilic digestion. Thermophilic digestion advantages are increased solids degradation capability, better dewatering, and increased bacterial degradation. Nevertheless, the disadvantages are requirements of high energy for heating, poorer quality supernatant containing a large amount of dissolved solids, odor and less process stability (Tchobanoglous et al., 2003).

Some of the advantages of anaerobic stabilization systems may include:

(1) The alternative of nutrient management;

(2) Opportunities for soil improvement;

(3) Methane emissions reduction;

(4) Production of renewable energy;

(5) Separation of organic waste from less preferred disposal options (EPA, 2015).

2.2.3 Aerobic Stabilization

Aerobic stabilization is a process that makes easy organic matter oxidation and converts organic matter into CO_2 and water with a limited supply of oxygen to microorganisms. Aerobic stabilization occurs with the microorganisms that are called mesophilic facultative bacteria, which grow in a range of temperatures between 20^oC- 37^oC and can alive under aerobic, anoxic, and anaerobic conditions. The aerobic stabilization typically comprises two or more tanks used to process and store the sludge. The tank(s) is aerated with typically coarse or fine bubble diffuser equipment and with a positive displacement or centrifugal blower are supplied the air (Woo, 2015).

The major objectives of aerobic stabilization are to produce stable biosolids that are convenient for various beneficial uses such as agricultural usage, pathogen reduction, and odor controlled (Woo, 2015).

Aerobic stabilization can be achieved by increasing the retention time with a good oxygen source up to 25 days and does not require any special competence beyond the normal operation of a wastewater treatment plant (PURE, 2012).

Typical sludge handling for small and medium-size wastewater treatment plants with aerobic stabilization is shown in Figure 2.5.

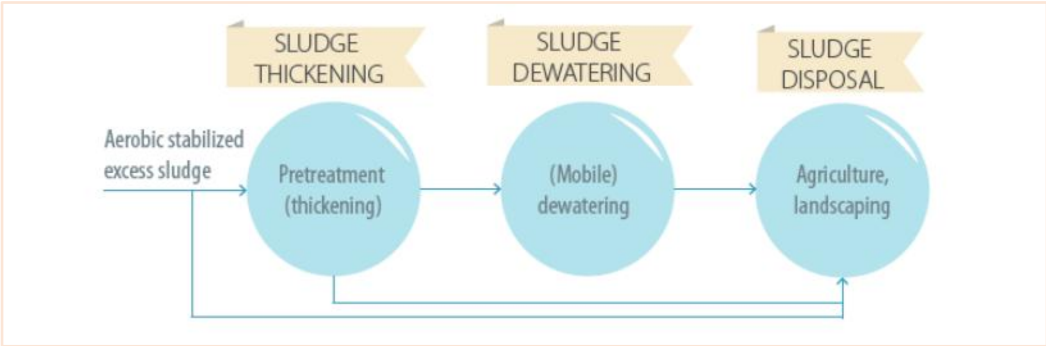

Figure 2.5 Typical sludge handling for small and medium-size wastewater treatment plants with aerobic stabilization (PURE, 2012)

According to Tchobanoglous et al. (2003), the advantages of aerobic stabilization compared with anaerobic stabilization are:

(1) In well operated aerobic stabilization the reduction of volatile solids nearly equal to anaerobic stabilization

(2) Low BOD concentration in the supernatant liquor,

(3) Biologically stable end product such as odorless, humus production,

(4) The basic fertilizer values in the sludge rising,

(5) To operate the process is quite easy,

(6) Low capital cost,

(7) Eligibility for digestion of nutrient-rich biosolids.

The disadvantages are:

(1) Higher operating cost cause of oxygen requirement

(2) Aerobically digested sludge has dewatering characteristics worse than anaerobically digested sludge

(3) Significantly influenced by the process, location, temperature, shape of the tank, the feed sludge concentration, and the tank material's type

(4) An additional disadvantage is the absence of useful end-product like methane recovery

2.3 Conditioning

Conditioning is a process of treatment for changing sludge characteristics in significant ways. In due course of the produce of biosolids, for both environmental and economic benefits conditioning must be carefully integrated to process. Usually, it does not occupy its own tank or other physical treatment but rather occurs between and within other processes (Dentel, 2001).

Conventionally, conditioning the sludge is done to improve its dewatering properties and afterward sludge is dewatered mechanically. Efficient sludge conditioning can be used to change the structure of sludge and the physical condition of water in sludge, it can also transform the water in sludge into free-floating water, and finally improve sludge dewatering qualities in order to get a high solid content. In practice, chemical conditioning is the method, which is applied in more common. It is familiar that the chemical conditioning mechanism destroys the colloidal structure of sludge, and flocculates the sludge via the mixed conditioners, like calcium oxide, ferric chloride, polyacrylamide, etc. On the other hand, the chemicals are expensive and they increase the cost of sludge management, therefore finding cheap and effective conditioners are very important (Chena et al., 2010; Liu et al., 2012).

2.4 Dewatering

The dewatering process of sludge is relatively simple: the dry solids content of the sludge is increased through different equipment types. Dewatering before drying can also be an important step in the drying process because if the solid sludge is drier, the drying step will be less costly. Usually, dewatering is made by using mechanical equipment such as filtration or centrifugation. In most of these, chemicals are used in order to accelerate the rate of dewatering or improve filtration quality. Today, belt filter presses and filter presses are the most common used dewatering devices for municipal wastewater sludge. There are also other dewatering processes (PURE, 2012; Novak, 2006).

Dewatering offers the following advantages (EPA, 2000 d):

(1) The volume of sludge is reduced; the cost of storage and transportation is reduced.

(2) Free liquids are eliminated before landfill disposal.

(3) In cases where sludge is to be incinerated or thermal dried, reducing fuel requirements.

(4) Material is produced and when it blends with a bulking agent, it will have enough void space and volatile solids.

(5) It eliminates ponding and runoff, the problems that may be faced when liquid on the land is not injected, but applied on the surface.

(6) It optimizes air drying and various stabilization processes.

2.4.1 Centrifuge

Centrifuges are generally used for dewatering stabilized sludge; dewatering of other sludges is also possible. Before, centrifuges have been used, especially in large wastewater treatment plants; today, they are used in medium and small wastewater treatment plants increasingly. The process is closed and compact, regular and reliable, and small capacity models are available too (PURE, 2012). The expected centrifuge dewatering equipment performances are given in Table 2.2. The schematic representation of a decanter centrifuge is shown in Figure 2.6.

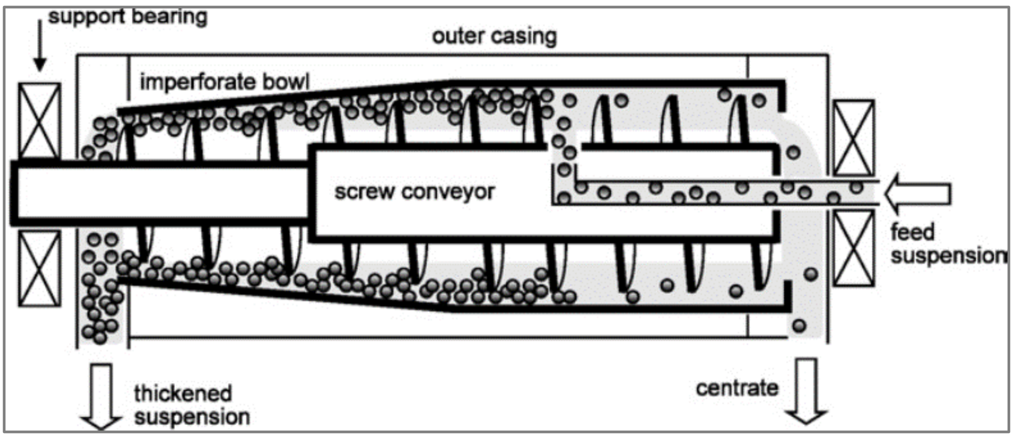

Figure 2.6 Schematic representation showing the essential features of a decanter centrifuge (Wakeman, 2007)

Table 2.2 Range of expected centrifuge performance (EPA, 2000 d)

Type of Wastewater Solids	Feed %TS	Polymer lb/DTS	Cake %TS
Primary Undigested	4-8	5-30	25-40
WAS Undigested	1-4	15-30	16-25
Primary + WAS undigested	2-4	5-16	25-35
Primary + WAS aerobic digested	1.5-3	15-30	16-25
Primary + WAS anaerobic digested	2-4	15-30	22-32
Primary anaerobic digested	2-4	8-12	25-35
WAS aerobic digested	1-4	20	18-21
Hi-Temp Aerobic	4-6	20-40	20-25
Hi-Temp Anaerobic	3-6	20-30	22-28
Lime Stabilized	4-6	15-25	20-28

Like all dewatering equipment, centrifuges require considerable investment and labor, and mechanical dewatering equipment may not be the alternative most cost-effectively to treatment plants which operating less than about 18,000 cubic meters per day (EPA, 2000 d).

2.4.2 Belt Pres

Belt presses are general mechanical dewatering equipment for dewatering most of the sludge. The belt filters have two continuous, tense filter cloths and sludge is supplied to the belt. The belt conveys the sludge to a consolidation zone where the upper and lower straps are gradually tightened under pressure where they move towards each other to form a cake is then pressed under ever-increasing pressure as it moves successively through a series of small-diameter rollers (Wakeman, 2007; EPA, 2000 c).

Low purchasing costs and consumption of low energy are the main advantages of belt presses. However, because the equipment is turned on, the belt press may have the following disadvantages: aerosol emissions, high levels of noise and ultimately undesirable odors (depending on sludge type). The other major disadvantage of the belt press is the nearly 40-50 piece of rollers in which operational attention is required and regular replacement (Cleverson et al., 2007). Schematic of a belt filter press and typical data of sludges dewatered on belt filter presses if given in Figure 2.7 and Table 2.3 respectively.

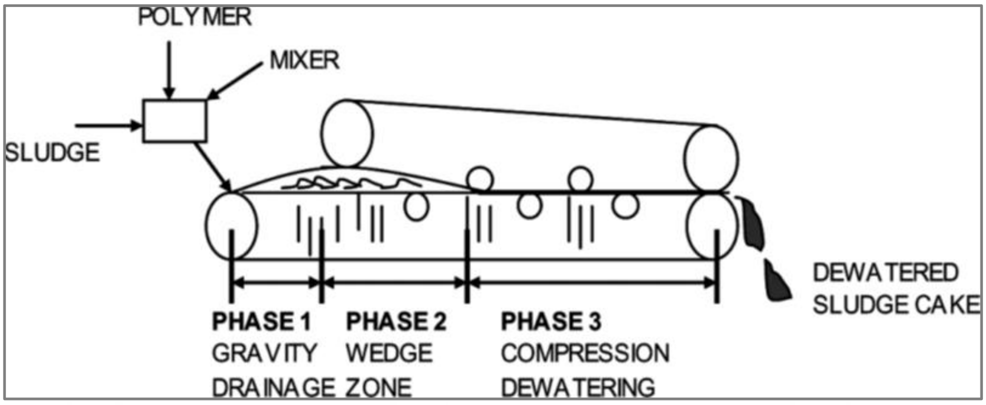

Figure 2.7 Belt filter press (Novak, 2006)

Table 2.3 Typical data for various types of dewatered sludges with belt presses (EPA, 2000 c)

Type of Wastewater Sludge	Total Feed Solids (percent)	Polymer (g/kg)	Total Cake Solids (percent)
Raw Primary	3 to 10	1 to 5	28 to 44
Raw WAS	0.5 to 4	1 to 10	20 to 35
Raw Primary + WAS	3 to 6	1 to 10	20 to 35
Anaerobically Digested Primary	3 to 10	1 to 5	25 to 36
Anaerobically Digested WAS	3 to 4	2 to 10	12 to 22
Anaerobically Digested Primary + WAS	3 to 9	2 to 8	18 to 44
Aerobically Digested Primary + WAS	1 to 3	2 to 8	12 to 20
Oxygen Activated WAS	1 to 3	4 to 10	15 to 23
Thermally Conditioned Primary + WAS	4 to 8	0	25 to 50

2.4.3Filter Press

Filter presses the main advantage is the ability to dewatered to the very high concentration of all types of sludge. The sludge concentrations to 45 to 50 % total solids can generally be achieved with appropriately conditioned sludges. Filter presses capture solid with high efficiency and as a result, produce relatively clear filtrate. The disadvantages of filter presses are that the process is batch and some manual assistance requirements for cake removal and generally the necessity of large quantities of conditioning chemicals (TUBİTAK, 2013). Recessed-plate filter press operating data is given in Table 2.4. Recessed-plate filter presses are achieved the highest solids content of cake and the highest percentage of solids retention compared to centrifuges and belt presses (EPA, 2000 b).

Table 2.4 Operating data of recess-plate filter press (EPA, 2000 b)

Sludge type	Feed solids concentration (%)	Cake solids concentration (%)	Typical cycle time (h)
Raw primary + activated	3–8	45–50	2–2.5
Raw primary + activated + $FeCl_3$	5–8	40–45	3–4
Primary + activated + $FeCl_3$ digested	6–8	40	3
Tertiary + lime	8	55	1.5

2.4.4 Solar Drying

When sludge volume reduction and dewatering, mechanical processes like a centrifuge, belt press and filter press are usually used (Chen et al., 2002). These are dewatered sludge with a moisture content of nearly 75–80 percent. The remaining sludge water content can only be removed by thermal processes. On the other hand, sludge can be dewatered extendedly in solar drying plants, which provide higher evaporation rates, thus realized significant sludge weight and volume reduction in shorter time periods. Solar drying is also defined rather low capital investment and operational cost. Furthermore, the reduction of sludge mass is closely related to low handling, transport and disposal costs and the final product is suitable for combustion to produce energy, or agricultural reuse (Mathioudakis et al., 2009).

In regions where naturally present hot and dry weather conditions are, solar drying has become an economically viable sludge dewatering technique. Unlike traditional drying processes, the evaporation energy demand is entirely met by solar energy and the electrical energy consumption is reduced more than four times (Öğleni & Özdemir, 2010).

Disadvantages of solar drying are the requirement of a large scale area to spread out the sludge, climate influences on the performance of plant such cold weather have a negative effect, sludge cake get out of the plant slowly due to long retention time.

The flow scheme of typical mechanical dewatering units is given in Figure 2.8. In Table 2.5, the advantages and disadvantages of Centrifuge, Belt-Press, and Filter press and solar drying plants, which are generally used in sludge dewatering, are compared.

Table 2.5 Various dewatering methods comparison (Fronhofer, 2015; Cleverson et al., 2007)

Dewatering Methods	Advantages	Disadvantages
Centrifuge	• Reduces the number of units for large plants. • Odor and process fluids are held. • The operator area is usually clean. • Preventative care is made less frequently.	• The energy consumption is so higher • The polymer usage is higher. • Repairs of the break down for generally take a long time. • Start-up and shutdown of the device take time • The operation must be continuous. • To feed instable sludge obstructs to watch the performance and make suitable arrangements. • Many units requirements to be economic
Belt-Press	• Low energy consumption • The polymer requirement is low. • It can be operated and maintained easily. • Start-up and shut-down the device easily and it is responsible for discontinuous operation • The process is observable allowing quick operator response to unstable conditions to avoid upsets. • It can be operated with rigid material well • Total Life Cycle Cost is cheaper • It can be dewatered a lot of sludge types.	• To hold odor and process fluids in a special enclosure. • To maintain and clean frequently • Cleaning is important in certain arrangements

Table 2.5 continues

Dewatering Methods	Advantages	Disadvantages
Filter -press	• If sludge is conditioned suitable, solids capture is excellent. • Low requirements of conditioning chemical • To maintain is easy • Suitable to daily operations. • The period can be completed in a 2-5 hour. • In 100 to 225 psi range filtration pressure	• It operates with a batch process. • System is complicated • Dosage is affected by the variable flow rate • High labor requirements • The operation and maintenance costs are too high • Large area requirement for press and system's accessory • To maintain and clean frequently • At the end of the period, the cake can be a wet cause of inappropriate conditioning or blinded cloth. • Discharge system cost is too high • To hold odor is difficult.
Solar Drying Plants	• Low construction cost • Operational simplicity • Electrical energy and chemical products consumption is lowest • Cake with high solid content	• Large area required • Climate influence considerably on the performance of the operation • Slow removal of the sludge cake

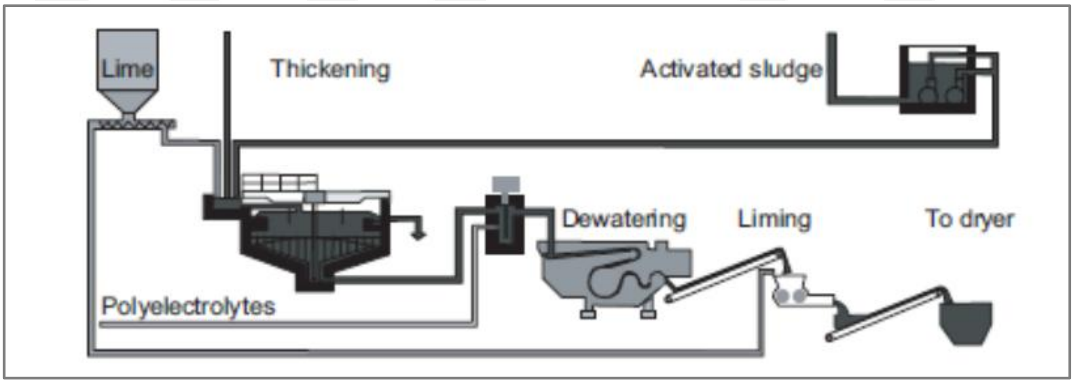

Figure 2.8 Typical Mechanical Dewatering of Sludge (Chen et al., 2002)

2.5 Thermal Drying

Thermal drying is a technology often used to increase the calorific value of the sludge for incineration significantly reduces the water content of the sludge. In addition, sludge drying for agricultural use is possible with thermal drying but it is an expensive way and isn't preferred. Evaporation of water from the sludge increases the dry solids content and reduces both the volume and weight. Although the dry solids content of sludge typically between 20 and 30 percent after dewatering, between 50 and 90 percent after thermal drying (PURE, 2012).

Advantages of thermal drying are:

(1) Relatively small area requirements compared with other stabilization processes,

(2) May designed to accept a variety of sludge characteristics,

(3) Greatly volume reduction,

(4) To produce a well marketable product (EPA, 2006).

Disadvantages are:

(1) Substantial capital cost requirement,

(2) A large amount of energy requirement,

(3) Achieves an explosive hazard from dust produced in the drying process,

(4) For operation and maintenance, skilled labor requirement,

(5) Nuisance odors may be produced

(6) End-product's offensive odor might affect its value and marketability (EPA, 2006).

2.5.1 Direct Dryer

In the direct dryers, for evaporating the remaining water in sludge, hot gases coming from the combustion of fuel or sludge is contacted with the dewatered sludge in the dryer. Drum, rotary, bell, spray and fluidized bed dryers are types of direct dryers. It has a mostly convective heat transfer mechanism and the evaporated water joins the hot gas stream (Peregrina et al., 2006).

Direct dryers have simpler designs, however, the vapor released should be separated from the drying agent, and it should be recycled for energy saving (Chen et al., 2002). The dried product of direct dryers is usually uniform in structure, size, and durability. Generally, dried product (usually undersized fine particles) must mix into the sludge, to increase the solids content of the sludge and avoid "sticky" or "plastic" phase condition. This situation occurs in mixtures with between 40 and 60 % solids content, and this causes the material difficult to mix and move inside the dryer (EPA, 2006).

2.5.2 Indirect Dryer

In the indirect dryers, the sludge never comes into direct contact with the heating agent separated by metal walls. The heat transfer is mostly conductive and it occurs through the dryer walls. The thermal oil or hot gas is separated from the dewatered sludge and the evaporated water is not mixed into the heating fluid (Peregrin et al., 2006; EPA, 2006)

Since indirect dryers produce smaller amounts of gas, most of their designs are closed-cycle integrated heat recovery and/or deodorization units. Indirect dryers are connected to heat transfer from a heated surface, and since the dewatered sludge relatively wet (about 25 percent of the solids content), the use of the sludge and the heated surface is a major problem. Since there is no airflow to disperse or shred the wet sludge, mechanical mixing should be designed to prevent clogging of the heating surface, particularly in the solid zone ranging from 55 to 70 percent in the adhesive region. Depending on the need for the dried sludge's final moisture content, one or two-stage indirect drying systems will be used (Tyzack, 1990).

Indirect dryers' explosion risk is lower than direct dryers because of produce dust lesser during the drying process. On the other hand, the product of indirect dryers is prone to be dustier than an end-product from a direct dryer. Lastly, in indirect dryers often oversized pellets are produced, which is not as admirable in the agricultural market (EPA, 2006).

2.6 Composting

Sludge composting is decomposed organic matter into a stable end-product is considered an environmentally friendly process. Furthermore, the metabolic heat generated during the thermophilic phase of the composting process is achieved at high temperatures in the range of 50-70°C, which is efficient in destroying pathogens and increasing the biodegradation of different organic micropollutants. This ensures that the final product is used as a fertilizer safely or soil conditioner (González et al., 2018).

The optimum conditions are 50 percent water content, carbon/nitrogen ratio is about 25 to 30, and the temperature is 55°C. The sludge's carbon-nitrogen content is low (5 to 10) when it is rich in nutrients, and its moisture content is also high. When the addition of dry sawdust in which the carbon/nitrogen ratio is 500, it can change both the moisture and the carbon/nitrogen ratio. Other materials such as mulch garden waste, forest waste, and chopped newspapers can be used for this purpose (UNEP, 2000).

The aerated static pile and the windrow process are the two most known composting methods. In the aerated static pile method, the wood chips are bulking agents, mixed with the dewatered sludge. In the windrow process methods, the mixing and elimination operations are like aerated static pile methods. Both composting periods are between 21 and 28 day and systems can be covered or enclosed (Scholz, 2006).

2.7 Sludge Reuse and Final Disposal Methods

Nowadays, sludge managements distinguish a search for new ways of reusing sludge. Generally, incineration, gasification, co-firing of dried sludge in the cement works and pyrolysis belong among the proper solutions of sludge disposal. There are two different ways, the first is incinerating the sludge for energy production and the second way is transforming sludge into a new product (Racek et al., 2019).

In addition to this, agricultural usage and landfilling are used as cheaper options. However, the advantages and disadvantages of these methods are still being discussed.

2.7.1Gasification

Gasification is a thermal process, in which the presence of the reactive atmosphere, air or steam, the sludge' carbon content is converted to a combustible gas and ash (Samolada and Zabaniotou, 2013). The gasification process uses heat, pressure, and steam to convert sludge into syngas and other end-products such as char or slag, oils and reaction water. The syngas is a mixture of CO, H_2 and other gases. The syngas's heating value is around 4 MJ/m^3 (Spinosa et al., 2011). Compared with incineration, gasification can prevent problems like the need for additional fuel, SOx, NOx, the potential production of heavy metals, fly ash, chlorinated dibenzodioxins, and potential production of dibenzofurans. It works best if dewatered sludge is used and the sludge dried solids content over 90% (Spinosa et al., 2011; Marrero et al., 2003).

The content of the energy in the gas produced by gasification, feed fuel, reactor type and so on. It depends on many factors. Therefore, basic research on the effects of sludge on gasification is important for obtaining a desired gas for electricity generation (Fytili & Zabaniotou, 2008).

The major advantages of the gasification process are:

(1) dioxins are not composed,
(2) the end product is a high-quality product of carbon conversion, nitrogen concentration falls below 30 mg/Nm^3,
(3) the gasifier is less than the cost of installation according to atmospheric pressure conditions,
(4) easy to control,
(5) turbulent movement of solids temperature ensures constant temperature,
(6) the product needs no more improvement (Salan, 2014).

2.7.2 Pyrolysis

Pyrolysis is the thermal degradation process in an inert atmosphere. The condensable and non-condensable gases and solid product vapors such as char is produced by pyrolysis. If pyrolysis is compared with gasification, gasification converts organic matter into flammable gas or syngas, oxygen requirements for total combustion are 20 to 40 percent; on the other hand, pyrolysis is a thermochemical reaction carried out theoretically inert atmosphere and in 500-1000 °C range of temperatures. Depending on conditions of o process, pyrolysis can mainly aim at obtaining coal, liquid or gas (Fonts et al., 2012). The flow scheme of pyrolysis is given in Figure 2.9.

In pyrolysis, the particle size of the raw material and residence time of vapor-phase products are important but the main process parameters temperature, residence time and heating rate. These parameters affect the extent of char formation, the contact between gases and chars, and the degradation of hydrocarbon gases. During pyrolysis, the temperature ranges from 220 °C - 900 °C. The raw material residence time alters from a few seconds up to several hours. Generally, high temperatures and long residence time support the production of gas and char while minimizing the production of oils (Agar et al., 2018).

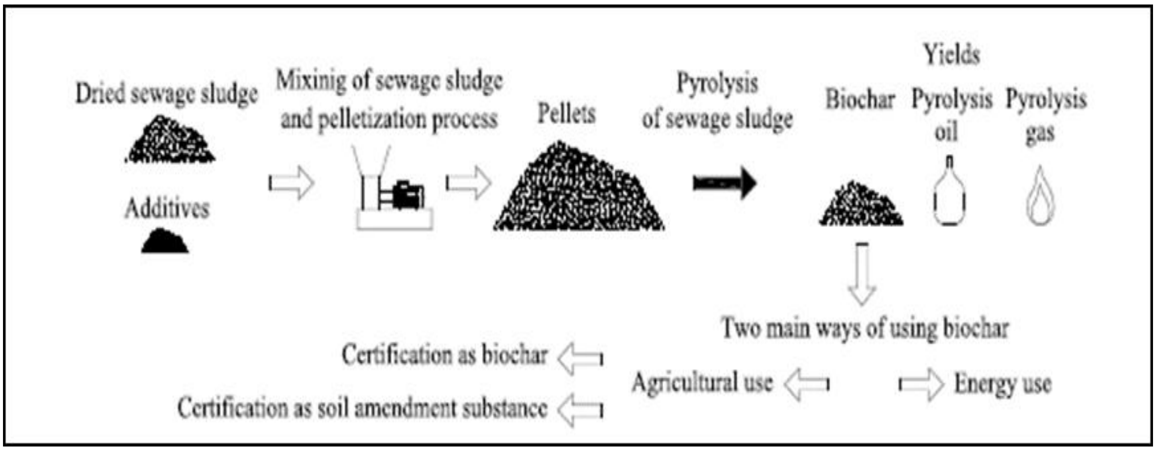

Figure 2.9 Pyrolis flowing diagram (Racek et al., 2019)

2.7.3 Landfilling

Disposal of sludge into landfills is thought a beneficial use only due to the fact that sludge comprises methane for energy production. However, methane treatment in existing wastewater treatment plants is relatively rare. However, existing landfills have a limited capacity, therefore alternative useful uses are of greater interest (Samolada & Zabaniotou, 2013).

Disposal of sludge into a landfill provides that they do not contaminate surface waters or groundwater. The high water content of the sludges generally makes transporting wet sludge to a landfill uneconomical, so the sludges are dewatered before being disposed of. In small plants, sludge can be buried in or near the plants. Disposal of sludge in landfills is labor-intensive due to trench digging, adding sludge and covering the area with topsoil (Scholz, 2006).

2.7.4 Agricultural Usage

The sludge contains nitrogen and phosphorus and these elements provide unique fertilization benefits to the sludge. However, the sludge may also contain various other elements, such as heavy metals that when enter the food chain can be harmful to the human body. In addition, sludges include pathogenic organisms and maybe an odor source. The presence of organic compounds in sludge like polyaromatic hydrocarbons (PAHs), adsorbable organic halides (AOX) and polychlorinated biphenyls (PCBs) may limit agricultural usage (Fytili & Zabaniotou, 2008; PURE, 2012; Scholz, 2006).

In agricultural usage, sludge is applied on land once or twice a year, but sludge is being produced year-round. Because of this situation, both sludge storage and large-scale land is required. On the other hand, transporting the sludge to agricultural land can pose problems because it is produced in urban areas. These are some technical problems are given above that arise face agricultural usage.

Generally, sludge is applied on land after the only stabilization. In some cases, before the sludge can be applied to agricultural land depending on the crop to be grown, it has pasteurization or disinfection requirements (Scholz, 2006).

2.7.5 Incineration

The sludge has calorific values range of between 20,000-50,000 kJ/kgs like conventional fossil fuels, coal, and oil. So, dried sludge incinerated without adding any fuel maybe. Actually, the calorific value is significantly reduced by remaining water in the sludge, so sludge has to be dewatered effectively before combustion. Designs of incineration generally rely on enough heat production to evaporate the remaining water from the sludge. The sludge may be incinerated with municipal waste too (Scholz, 2006).

The advantages of incineration are;

(1) High sludge volume reduction; after incineration, the final sludge volume is approximately 10% of mechanical dewatering.

(2) Toxic organic compounds' thermal ruination

(3) The incineration provides to recover the energy content of sludge which depending on sludge's high calorific value;

(4) Odor minimization(Fytili & Zabaniotou, 2008).

In incineration, there are two furnace types used are multiple-hearth incineration and fluidized bed incineration. Multiple-hearth incineration composes of a series of floors in a cylindrical tower. The sludge is put on top and slowly falls to the lower floors. The sludge is carried with rabble arms on the ground. The significant combustion takes place at the lower levels, and dried sludge is produced in these levels with upper-level heat. In contrast, fluidized bed incineration composes of a cylindrical chamber containing about 1.0 m of sand on a heat-resistant steel grid. The injection of compressed air is fluidized the bed, and under pressure, sludge is injected into the sand. Then the organic matter burns and water evaporates (Schloz, 2006). The differences between multiple-heart furnaces and fluidized bed furnaces are that in multiple-heart furnaces, sludge, which is dewatered by mechanically, is burned generally, on the other hand in fluidized bed furnaces can be burned both wet and semi-dried sludge. Modern fluidized bed incineration plants have become even more attractive in terms of both capital and operating costs compared to the traditional multiple heart incineration plant type (Fytili & Zabaniotou, 2008).

2.7.6 *Co-Incineration of Dried Sludge in Cement Plants*

The sludge has high calorific value and carbon content, thus sludge may be used as an alternative fuel for the cement plants. Production of cement has large amounts of natural non-renewable resource requirements, such as limestone and coal. Co-Incineration of Dried Sludge in Cement Plants can't reduce the consumption of natural sources but can ensure recovery of sludge, and sustainable development of the cement industry in an effective way (Li & Zhang, 2011).

In industrial processes that require a large amount of energy, the sewage sludge can be used as a secondary fuel. A good example of this is the cement industry, which to heat the cement kiln has a huge fuel requirement. As a result, usually, the cement industry uses sludge as secondary fuel in clinker kilns (Gálvez, 2007).

Co-Incineration of Dried Sludge as an alternative fuel in existing cement plants and inclusion of ash in the end-product seems to be the most promising output compared to solo incineration furnaces (Fytili & Zabaniotou, 2008).

CHAPTER THREE
EXISTING WASTEWATER TREATMENT PLANTS IN ANTALYA

3.1 Antalya City

The province of Antalya has a surface area of 20,723 km². The population of the province is 2,426,356 and the annual average population increase is 2.62%. Antalya, within 81 provinces, is the 2nd province in letting in immigrants and the 4th province in immigrating

Antalya, located in the south of Turkey's Mediterranean coast is a tourist center. The length of the Antalya coast, designated as the Turkish Riviera, is about 630 km. There are a total of 19 districts in Antalya (Aksu, Döşemealtı, Kepez, Konyaaltı, Muratpaşa, Akseki, Alanya, Elmalı, Finike, Gazipaşa, Gündoğmuş, Kaş, Korkuteli, Kumluca, Manavgat, Serik, Demre, İbradı, Kemer).

In the province of Antalya, the Mediterranean climate prevails with hot and dry summers and mild and rainy winters. The chilling and semi-continental climate is witnessed in the inner parts of the region. The average temperature in summer is between 30-34 degrees. In January, the average temperature varies between 9-15 degrees. There are almost no meteorological events such as snowfall and frost in the city center.

The average annual relative humidity in the province is around 64%. In the coastal area of Antalya, summers are long-lasting and warn. Winters are mild. There is no rain during summer, and it rains December, January and very rarely during spring and autumn. The weather is overcast and rainy only 40-50 days within a year. Antalya is one of the rare regions open to tourism activities for 12 months of the year with an average of 300 sunny days per year and an average annual temperature of 18.7 degrees. You can swim in Antalya for 9 months a year. The vegetation is composed of short and green trees called scrubs as a result of the Mediterranean climate (Antalya Metropolitan Mayor, n.d.)

Tourism, trade, and agriculture are the most important segments in the economy, industry, animal husbandry, and mining activities are also developing recently.

Although Antalya is considered as the 7th developed province in Turkey it is below the average of Turkey in the field of industry. The main reason for this is that tourism and agricultural activities are at the forefront of Antalya. As a result of the industrialization initiatives that started with the Sumerbank and Antbirlik facilities in the 1950s, there are about 200 companies in the industry register of Antalya. The share of the industrial sector in the gross product is 7 %. The share of industry in Antalya's national income is only 4.3 % (Antalya Metropolitan Mayor, n.d.)

In terms of agricultural potential and ecological compliance, Antalya has an important place in Turkish agriculture. One-fifth of Antalya's land is cultivated. The coastal area is suitable for greenhouse cultivation as well as for growing tropical plants such as oranges, bananas, and avocados. Fruit species such as apple, pear, and quince can be cultivated in the inner parts of the region. In parallel with the rapid development of the city, the agricultural sector has undergone profound structural changes. In 1970, three-quarters of the population's income was from the agricultural sector, while in 2000 this rate decreased to 49% (Antalya Metropolitan Mayor, n.d.).

Antalya is a major contributor to the national economy with its leadership in the tourism sector. The figures provided below are the biggest indicators of this and tourism is one of the most important economic locomotives of the city.

There are 905 facilities, 232,000 rooms, 500,000 beds (42% of the total number of beds in Turkey), 395 5 star facilities (more than all of Spain), 25 tourism centers, 6 Cultural and Tourism Protection and Development Areas, 934 protected areas, 3,017 immovable cultural assets, 210 Blue flags (44% of the total blue flags in Turkey - 1st place in the world), 10 clubs, 24 golf courses (a total of 32 in Turkey), 184 football fields (141 of them owned by hotels) and 63 % of foreign visitors to our country stay here (Antalya Metropolitan Mayor, n.d.).

3.2 Brief Overview of Wastewater Treatment Plants in Antalya

3.2.1 Domestic/Municipal Wastewater Treatment Plants

Wastewater connected to infrastructure systems (excluding Finike, Gündoğmuş and Ibradı Districts) is treated and disposed of in thirty-three domestic/municipal wastewater treatment plants. Flow, capacity, commissioning date, process and discharge information related to the wastewater treatment plants are given in Table 3.1.

Domestic wastewater formed in the central districts of Konyaaltı, Kepez and Döşemealti are treated in Hurma Wastewater Treatment Plant, and domestic wastewater produced in Muratpaşa and Aksu districts are treated in Lara Advanced Biological Wastewater Treatment Plant (RTMEU, 2018). Detailed information about Hurma and Lara WWTPs can be found in the following sections.

According to information received from Antalya Metropolitan Municipality ASAT General Directorate Wastewater treatment plants in Finike and Ibradı districts are under construction and are planned to be operational as soon as possible. In the Gündoğmuş district, the plant, of which the construction was completed; is not yet commissioned due to lack of infrastructure.

All domestic/municipal wastewater treatment plants, except for Turkler and Boğazkent Wastewater Treatment Plants, listed in Table 3.1 is operated by Antalya Metropolitan Municipality ASAT General Directorate. Turkler and Bogazkent Wastewater Treatment Plants are currently operated by Turas Tur. Tic. Inc.

Table 3.1 Municipal wastewater treatment plant in Antalya

WWTP	**Commissioning Date**	**Population Equivalent**	**Capacity (m^3/d)**	**Process**	**Discharge**
Hurma	2001-2011	1,400,000	210,000	Bardenpho Process (5 stage)	Sea Discharge
Lara	2007	250,000	3,1250	Bardenpho Process (5 stage)	Sea Discharge
Elmalı	2012	25,000	2,300	EAAS*	DSI Water-Trench
Korkuteli	2012	80,000	14,900	EAAS	DSI Water-Trench
Beldibi	1983-1999	78,183	22,787	EAAS	Deep Sea Discharge
Göynük/ Kızıltepe	1991-2006	54,408	16,342	EAAS	Deep Sea Discharge
Kemer	1982-2006	71,300	21,415	EAAS	Deep Sea Discharge
Çamyuva	1994-2006	73,164	21,975	EAAS	Deep Sea Discharge
Tekirova	1992	32,616	9,000	EAAS	Deep Sea Discharge
Kumluca	2008	100,000	17,300	EAAS	Stream Discharge
Güzören	2015	1500	300	EAAS	Stream Discharge
Karaöz	2013	5,000	400	EAAS	Ground Discharge
Kaş	2006	36,000	5,400	EAAS	Deep Sea Discharge
Kalkan	2004	25,000	4,000	EAAS	Ground Discharge
Demre	2016	69,231	7,214	EAAS	Sea Discharge
Serik	1992-2015	80,000	25,000	EAAS	Stream Dıscharge
Belek 1	1992	65,500	13,100	EAAS	Sea Discharge
Belek 2	2001	90,400	22,600	EAAS	Sea Discharge

Tablo 3.1 continues

WWTP	Commissioning Date	Population Equivalent	Capacity (m^3/d)	Process	Discharge
Boğazkent	2006	55,000	11,000	EAAS	Stream Discharge
Çandır	-	-	200	EAAS	Stream Discharge
Manavgat	2012-2015	240,000	100,000	EAAS	Sea Discharge
Çolaklı	2000	50,000	15,000	EAAS	Deep Sea Discharge
Kumköy	2006	160,000	50,000	EAAS	Deep Sea Discharge
Titreyengöl	1986	35,000	10,725	EAAS	Deep Sea Discharge
Alanya	1996-2012	280,000	70,000	Activated Sludge+SBR*	Deep Sea Discharge
İncekum (Avsallar)	2002	75,000	15,000	EAAS	Deep Sea Discharge
Türkler	2009	59,194	15,000	EAAS	Deep Sea Discharge
Okurcalar	2008	46,000	20,000	EAAS	Deep Sea Discharge
Konaklı	2007	150,000	30,000	EAAS	Deep Sea Discharge
Oba/Tosmur /Cikcilli	2009	110,000	31,000	EAAS	Deep Sea Discharge
Mahmutlar	2007	11,7647	20,000	EAAS	Deep Sea Discharge
Gazipaşa	2012	45,000	8,800	MBR (Membrane Bioreactor)	Stream Discharge
Akseki	2015	5,000	500	EAAS	Underground

* EAAS: Extended Aeration Activated Sludge, SBR: Sequencing Batch Reactor

The maps in Figure 3.1, Figure 3.2, and Figure 3.3 that indicate the locations of these plants are provided below.

Figure 3.1 Wastewater treatment plants in the west of Antalya (adapted from Google Earth, 2019)

Figure 3.2 Wastewater treatment plants in the central district of Antalya (adapted from Google Earth, 2019)

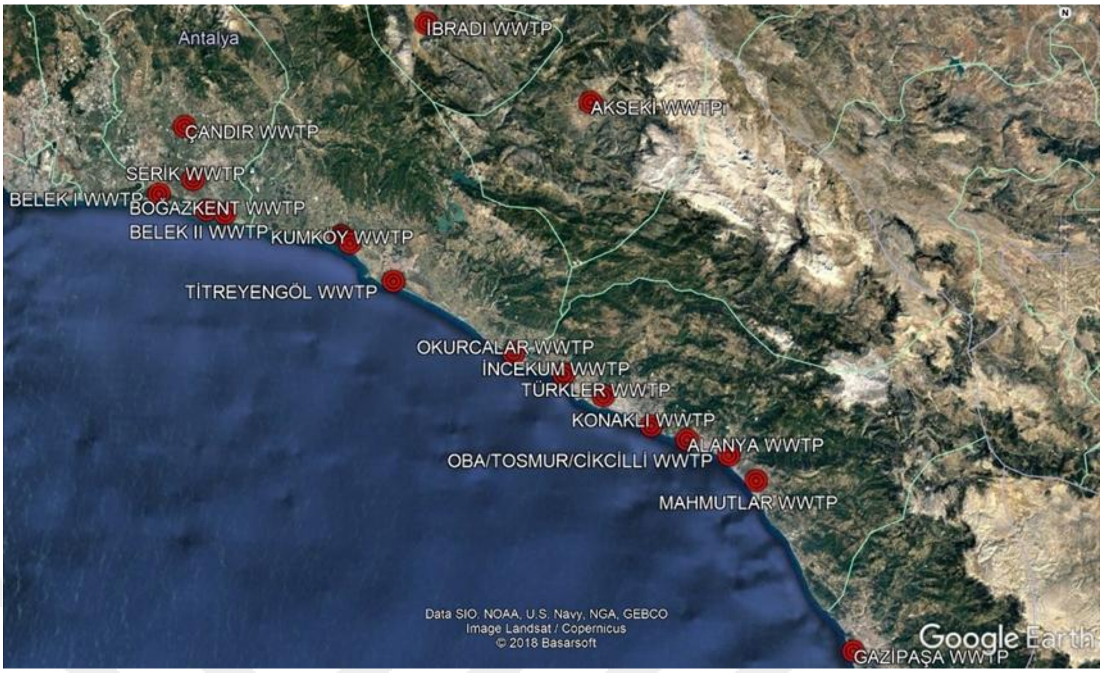

Figure 3.3 Wastewater treatment plants in the east of Antalya (adapted from Google Earth, 2019)

The ratio of the total population, who are provided with sewage services in Antalya, is 80% (RTMEU, 2018). In accordance with Article 32 of the Regulation on Water Pollution Control, hotels, motels, holiday villages, holiday complexes, and summer estates and industrial facilities with a population of more than 84 are obliged to establish and operate wastewater treatment plants. Table 3.2 indicates the capacity information of the domestic wastewater treatment plants established for the treatment of domestic wastewater that cannot be connected to the infrastructure system.

The places indicated as shopping centers in the table are the facilities established to meet the needs of tourists, especially on the roadsides between cities. In addition, as it can be seen from the table, wastewater of 1 bakery production facility, summer sites, hotels, 2 hospitals, 1 quarry, and airport are treated and disposed of in individual treatment plants.

The capacity information for the 22 domestic wastewater treatment plants established for the treatment of domestic wastewater by the aforementioned facilities is provided in Table.3.2 Particularly due to the lack of infrastructure systems in the Manavgat Çenger region where tourism facilities are dense, there is a need to establish a wastewater treatment plant by the hotels located in this region and the number of individual treatment plants is higher in this region.

Table 3.2 Individual domestic wastewater treatment plants

District	Plant	Capacity (m^3/d)
Aksu	Baked Products Manufacturing	25
	Vacation Homes	120
	A Group of Hotels	-
Kepez	Chamber of Commerce and Industry	40
Serik	Shopping Mall	50
	Shopping Mall	70
Muratpaşa	Airport	40
	Hotel	240
	Airport	4,500
Manavgat	Vacation Homes	110
	Hotel	660
	Hotel	614.5
	Hotel	350
	Hotel	770
	Hotel	360
Kumluca	Pension	60
Finike	Hotel	360
	Dwellings	360
	Dwellings	72
Demre	Hospital	40
Kaş	Hospital	38
	Mine	32.2

Hurma and Lara WWTP are the biggest capacity treatment plants of Antalya. Therefore, detailed information is given about these two plants in the scope of the thesis. The following information about the Hurma Wastewater Treatment Plant and Antalya Lara Advanced Wastewater Treatment Plant was obtained from the official website of ASAT.

Hurma Wastewater Treatment Plant

Sewage wastewater from the western part of the city is treated in Hurma Wastewater Treatment Plant located at the 16^{th} km of the Antalya-Kemer highway and it was established by the General Directorate of Antalya Water and Wastewater Administration (ASAT) on 17 February 1999. The settlement plan of the Hurma WWTP is given in Figure 3.4.

Figure 3.4 Overall settlement plan of the plant (ASAT, n.d)

The first stage of the Hurma Wastewater Treatment Plant was planned to serve 250,000 people and it was put into operation on 29 December 2001. The Second Stage was put into operation in January 2005 and the plant has reached a capacity to serve 500,000 people. The third stage was put into operation in April 2011. Following the operation of the third stage, the plant has reached a capacity of 210,000 m^3/day and serves a population equivalent to 1,400,000 people.

In Hurma Wastewater Treatment Plant, Carbon (C) - Nitrogen (N) - Phosphorus(P) removal is carried out by using the 5-stage Bardenpho Process and the plant operates with 98% efficiency. The treated wastewater is discharged 50 meters deep into the sea through a 5 km long discharge line.

The plant also includes sludge thermal drying and cogeneration plant with 150 tons/day capacity established for the disposal of approximately 100 tons of sludge with a content of 16-20% dry matter generated in the Hurma Wastewater Treatment Plant and 50 tons of sludge with a content of 22-24 % dry matter in the Lara Advanced Wastewater Treatment Plant. detailed information about Sludge Thermal Drying and Cogeneration Plant is given in Section 3.3 the flow scheme of the Hurma wastewater treatment plant is given in Figure 3.5.

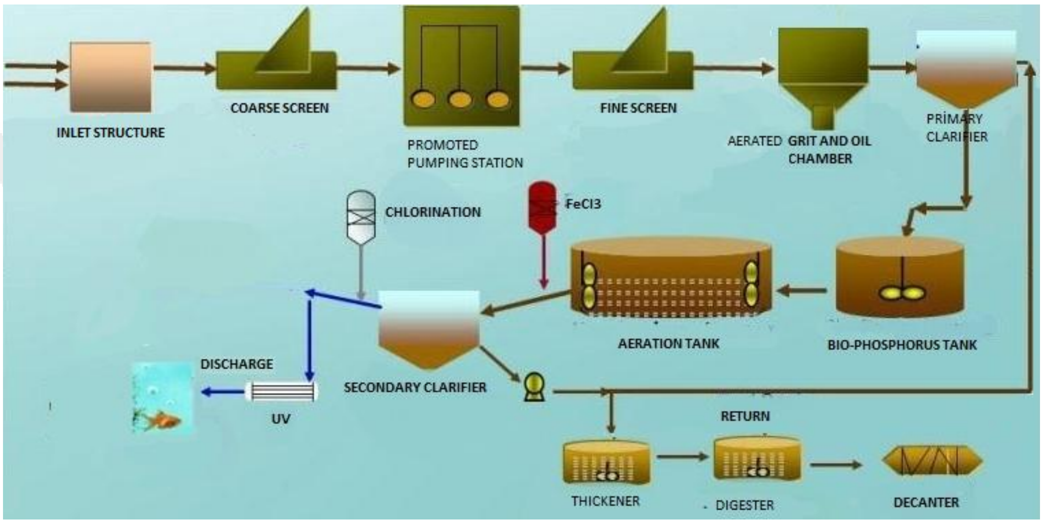

Figure 3.5 Hurma wastewater treatment plant flow scheme (ASAT, n.d)

Antalya Lara Advanced Wastewater Treatment Plant

Lara Advanced Wastewater Treatment Plant was established 17 km away from the city center and 250 m north of Lara Beach for the treatment of wastewater generated by the population and collected from the sewage network and wastewater generated by the touristic facilities in the region.

Lara Advanced Wastewater Treatment Plant has been designed in 4-stages. Each stage has a capacity of 31,250 m^3/day and the pre-treatment unit was put into an operation with a capacity equivalent to 500,000 people, whereas the biological treatment plant’s capacity is equivalent to 250,000 people.

The plant consists of physical treatment, biological treatment, and sludge dewatering units and deodorization unit, which operates with a wet scrubber system in order to solve the odor problem without affecting the surrounding settlements. The flow scheme of the plant is given in Figure 3.6. In addition, the treatment plant has 80 acres of green space and 12 acres of Olympic-sized turf football field on the aeration basin.

The high-quality effluent obtained in the plant is discharged at a point, which is 950 meters away from the land, 2,250 meters away from the Antalya Lara coast and at a depth of 22 meters. Some of the effluent is reused for landscape irrigation. Some seasonal plants are grown in the established greenhouse.

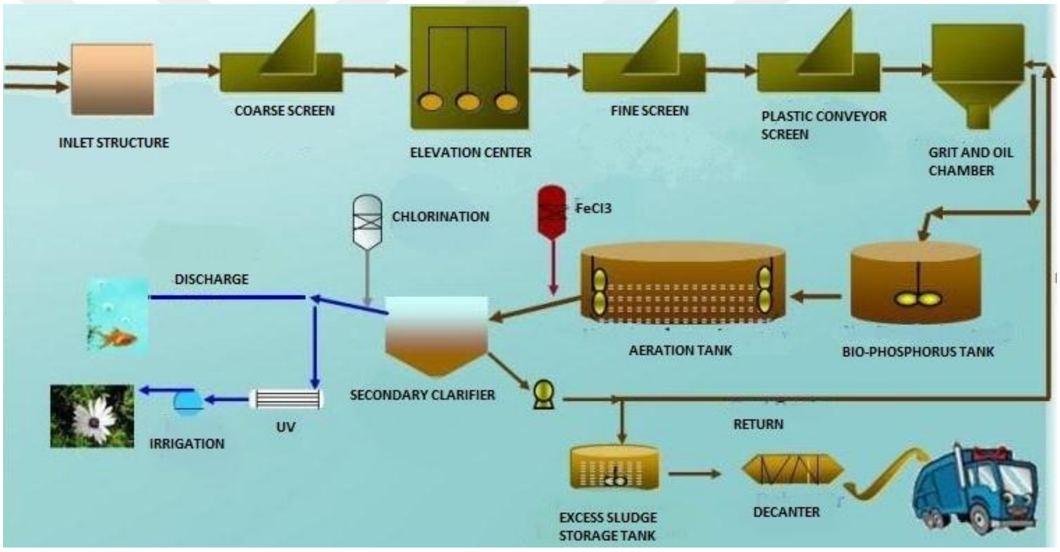

Figure 3.6 Lara advanced wastewater treatment plant flow scheme (ASAT, n.d)

3.2.2 Industrial Wastewater Treatment Plants

As mentioned in the previous chapters, the source of economic income for the province is primarily tourism, agriculture, and trade. The industry is also a new and developing resource. There is only one organized industrial zone in the city.

Antalya Organized Industrial Zone consists of three parts. Wastewater that is generated in the facilities operating here is treated at the treatment plant of the organized industrial zone and discharged to the wastewater infrastructure system of the General Directorate of Antalya Water and Wastewater Administration (ASAT). Detailed information about Antalya Organized Industrial Zone Wastewater Treatment Plant is provided in the following chapters.

Industrial activities outside the organized industrial zone are carried out in small industrial sites within the city center and districts. Small industrial sites are connected with the infrastructure system. Process and capacity information related to the individual industrial wastewater treatment plant and organized industrial zone wastewater treatment plants are given in Table.3.3.

Table 3.3 Individual industrial wastewater treatment plants

No	Sector	Process	Capacity (m^3/d)
1	Organized Industrial Zone	Extended Aeration Activated Sludge	20,000
2	Printing Press	Batch Reactor	7.9
3	Oil Production Plant	Extended Aeration Activated Sludge	385
4	Jam And Conserve Production Plant	Activated Sludge	490
5	Seed Production	Extended Aeratıon Activated Sludge	136
6	Dairy Plant	Activated Sludge	45
7	Beverage Plant	Activated Sludge	490
8	Fish Handling Plant	Activated Sludge	25
9	Fruit Juice Production	Activated Sludge	200
10	Fruit Processing Plant	Activated Sludge	6
11	Concrete Plant	Physical and Chemical	14
12	Energy Generation Plant	Physical	6,088
13	Recycling Plant	Physical	5
14	Gas Station	Physical	9
15	Recycling Plant	Physical	40

As can be seen from the table, although there are sectors with high pollution wastewater production, wastewater treatment plants excluding for the organized industrial zone, operate with low capacities. Most of the facilities, except for physical treatments, were constructed as a package treatment system. Except for the sludges, which are considered as hazardous wastes, the sludges formed are delivered to the nearest municipal wastewater treatment plant via sewage trucks and disposed of accordingly. Treatment sludges, which are considered hazardous waste, are delivered to licensed disposal facilities.

Antalya Organized Industrial Zone Wastewater Treatment Plant

According to the information received from Antalya Organized Industrial Zone, wastewater that originates from facilities operating in Antalya Organized Industrial Zone is treated in a wastewater treatment plant with a capacity of 20,000 m^3/day and discharged to Antalya Water and Wastewater Administration (ASAT) General Directorate wastewater infrastructure system. The first stage of the wastewater treatment plant with a capacity of 10,000 m^3/day was established and put into operation in 2003. According to the increasing demands, the following stage of the project with 10,000 m^3/day capacity was put into operation in 2007. The current capacity of the plant is 9,000-11,000 m^3/day, and the space allocated for stages 1 and 2 is 47,464 sqm. The plant has physical, chemical and biological treatment, sludge dewatering and deodorization units. The flow scheme of the wastewater treatment plant is given in Figure 3.7.

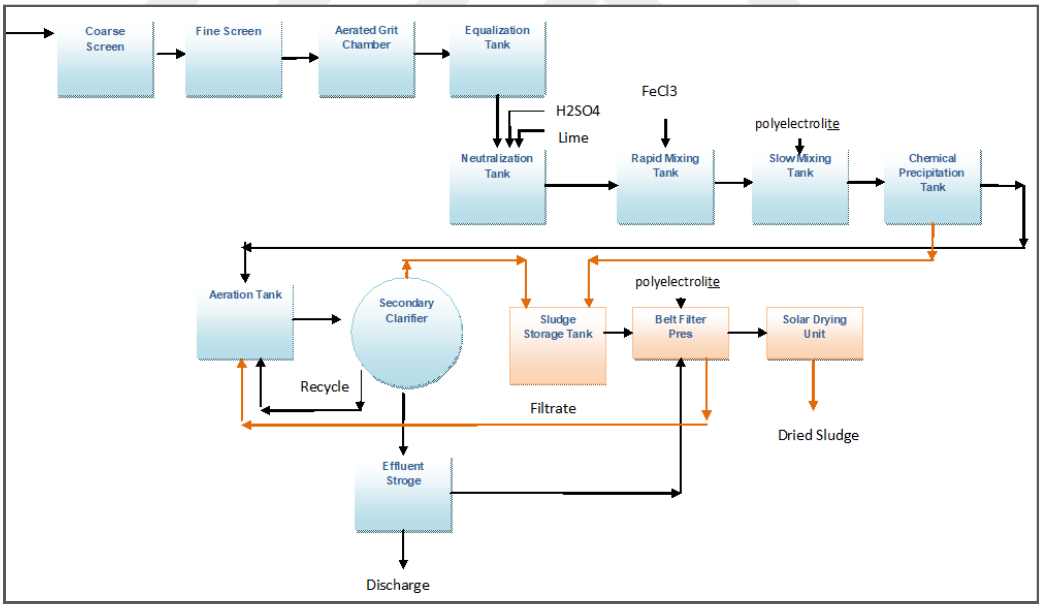

Figure 3.7 Antalya organized industrial zone wastewater treatment plant flow scheme [S. Kayhan, (personal communication, 10 December 2018)]

3.3 Sludge Generation and Current Sludge Removal Applications in Antalya

3.3.1 Sludge Production and Characteristics

3.3.1.1 Municipal/Domestic Treatment Sludges

The Antalya city population is nearly 2.4 million in 2017 and the produced sludge amount is nearly 430 tons /d (DM) from municipal wastewater treatment plants.

Sludge Thermal Drying and Cogeneration Plant were established in 2008 as an integrated part of Hurma and Lara Treatment Plants with a capacity of 150 tons/day in order to dispose of the sludge generated by these two plants. Today, only the sludge produced in the Hurma WWTP is dried. Dry sludge with 85-90% DM content is delivered to cement plants and disposed of as additional fuel.

Except for Hurma WWTP, treatment sludges formed in other plants with an average of 22% DM content are delivered to individual solar/thermal drying plants and are then delivered for final disposal. There are a total of four such plants, which three are in Korkuteli and one in Manavgat, had previously been operated by the Ministry of Environment and Urbanization under Non-Hazardous Waste Recycling License, but two of them do not carry out sludge drying due to various reasons. The other two continue with their operations under license.

The amount of daily treatment sludge in 2015, 2016 and 2017 in the wastewater treatment plants, which are currently under operation, is provided in Table 3.4.

Table 3.4 Amount of sludge generated in 2015, 2016 and 2017

District	WWTP	Capacity	Sludge Total ton/d (2015)	Sludge Total ton/d (2016)	Sludge Total ton/d (2017)
KONYAALTI KEPEZ DÖŞEMEALTI	Hurma	210,000	140	168.2	181.19
MURATPAŞA AKSU	Lara	31,250	35	44.5	46.8
ELMALI	Elmalı	2,328	2	2.97	3.8
KORKUTELİ	Korkuteli	14,960	2	5.9	7.1
KEMER	Kemer	21,415	8	5.3	5.9
	Beldibi	22,787	3	3.8	4
	Göynük/Kızıltepe	16,342	6	2.3	2.6
	Çamyuva	21,975	8	3.1	3.7
	Tekirova	9,000	4	3.8	4.7
KUMLUCA	Kumluca	17,300	8	9.1	9.4
	Karaöz	400	-	-	-
	Güzören				
KAŞ	Kaş	5,400	2	2	1.8
	Kalkan	4,000	2	0.3	0.9
DEMRE	Demre	8,237	-	-	0.1
SERİK	Serik	25,000	6	6.9	8.2
	Belek 1	13,100	5	6.2	9.7
	Belek 2	22,600	9	3.8	15.3
	Boğazkent	11,000	5	4	4
MANAVGAT	Çolaklı	15,000	12	9.8	8.1
	Kumköy	50,000	23	5.1	25.4
	Titreyengöl	10,725	4	2.9	4.6
	Manavgat	100,000	38	25.2	28.8
ALANYA	İncekum (Avsallar)	15,000	8	7.4	6.6
	Türkler	15,000	8	3.4	3.4
	Okurcalar	20,000	8	3.2	4.5
	Konaklı	30,000	12	3.6	8
	Alanya	70,000	45	6.2	10.1
	Oba/Tosmur/ Cikcilli	31,000	12	8.9	8.1
	Mahmutlar	20,000	9	7	12.3
GAZİPAŞA	Gazipaşa	8,800	1	1.1	1.7
AKSEKİ	Akseki	400	-	-	-
		TOTAL	425	356	430.8

Sludge generation in tourism intensive regions, such as Kemer, Manavgat and Alanya, and in some parts of Serik, is lower in 2016 when compared with the amounts of 2015.

It is considered that this is related to the number of tourists visiting the city. In Oba/Tosmur/Cikcilli, Incekum, Çolaklı, and Kaş treatment plants, decreases in daily sludge generation are observed for 2017 when compared with 2016; and the amount was stable in Turkler Wastewater Treatment Plant, however, it increased in all other plants. All these variations are considered to be related to population growth and tourism intensity.

Although there are no sludge dewatering units in Karaöz, Güzören and Candır WWTPs, which operate as package treatment plants, the sludges generated in these low capacity plants are delivered to the nearest municipal wastewater treatment plants for disposal via sewage trucks.

All sludges generated in the individual domestic wastewater treatment plants provided in Table 3.4, except for physical treatment, are collected via sewage trucks and delivered to the nearest municipal wastewater treatment plant for disposal.

3.3.1.2 Industrial Sludge

Although the economy of the province is primarily based on tourism, agriculture, and trade, the industry is a developing source of income. Although there is only one organized industrial zone; other industrial activities are carried out in small industrial sites within the central district and other districts. There are also individual industrial facilities; however, their numbers are very small.

Wastewater generated in all plants operating within Antalya Organized Industrial Zone is treated in a wastewater treatment plant with a capacity of 20,000 m^3/day and discharged to Antalya Water and Wastewater Administration (ASAT) General Directorate wastewater infrastructure system. The map showing the Organized Industrial Zone Wastewater Treatment Plant is provided in Figure 3.8.

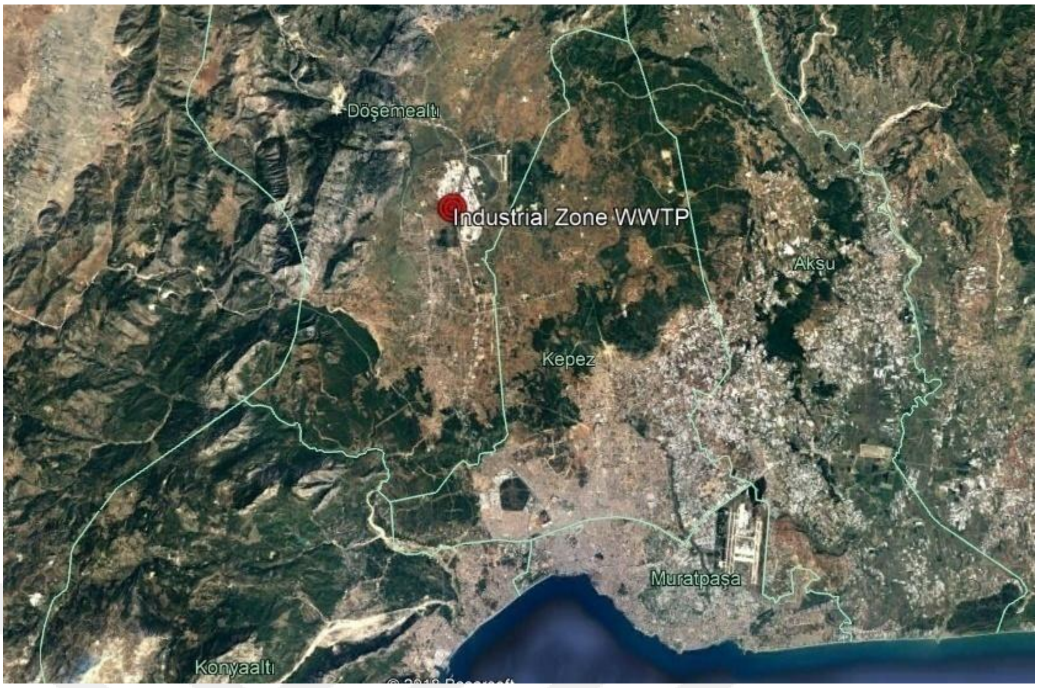

Figure 3.8 Antalya organized industrial zone wastewater (adapted from Google Earth, 2019)

Approximately 20-25 tons/day (DM) of sludge generated in the plant is dried at the greenhouse type solar drying plant integrated to the wastewater treatment plant of the organized industrial zone and delivered for disposal to cement plants to be used additional fuel. The physical-chemical analysis of the sludge is given in Table 3.5 (RTMEU, 2018).

Table 3.5 Physical-chemical analysis of Antalya organized industry zone WWTP treatment sludge

Parameter	**Result**	**Method of Analysis**
Appearance / odor	Black/ with odor	
pH (aqueous solution)	7.45	TS 8753 EN 12176
Water content (weight %)	84.45	TS 9546 EN 12880
Solid content (weight %)	15.58	TS 9546 EN 12880
Organic matter (weight %)	10.04	TS 8336
Inorganic matter (weight %)	5.54	TS 8336
Total organic carbon (mg/kg)	3,523 (0,35%)	SM 5310 B
Oil - grease (mg/L)	5,540 (0,55%)	ASTM D7066
Upper calorific value (cal/g)*	3,523	ASTM D5865
Total sulfur (%) *	0.930	ASTM D4239

* For sample dried under 105°C

The generated industrial sludge is disposed of with the waste code 19 08 13, which is included in the Annex Lists of Waste Management Regulation published in the Official Gazette dated 02.04.2015 and numbered 29314.

Information on the wastewater treatment plants of the individual industrial plants established in the regions where the infrastructure system is not available is provided in Table 3.3. As it is shown on the table, the capacities of these plants are very low.

The sludge generated in the printing press is delivered to licensed disposal facilities with the waste code 19 08 11. The sludge formed in other plants is delivered to the nearest municipal wastewater treatment plant via sewage trucks and disposed of accordingly.

3.4 Problems with Current Applications

In relation to the treatment sludge problems experienced, the priority in Antalya is the differences in the amount of sludge that occurs during the year due to variations in wastewater flow rates with the tourists visiting the city. This causes the management to be difficult due to extra costs related to the formation of a high amount of sludge when the population of the city is considered. Since Antalya is the most significant tourism city in Turkey, the number of domestic and foreign tourists visiting the city during the year is very high. An increase in the number of tourists starts during spring months and reaches record-breaking levels during summer. The population of the city increases by five times and more when compared with winter months. Due to the fact that the treatment plants, which are designed with this in mind, operate at full capacity, maximum levels of sludge formation occur in the summer months.

The number of domestic and foreign tourists visiting the city in 2015 by months is given in Figure 3.9. As the graph indicates, the number of tourists reaches maximum levels especially during the months of July and August. According to the data obtained from the official website of Antalya Provincial Directorate of Culture and

Tourism, the total number of domestic and foreign tourists visited the city in 2015 is 11.331.840 this number is about 5 times the city's population in that year.

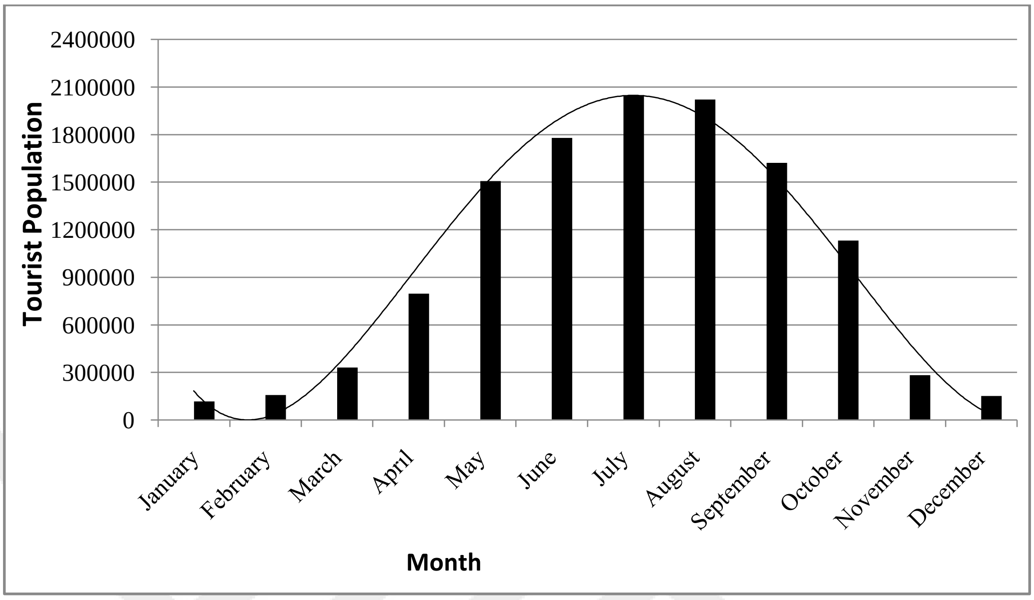

Figure 3.9 Number of domestic and foreign tourists visiting the city in 2015 by months

Sludge amounts in 2015, 2016 and 2017 are given in Figure 3.10, 3.11, and 3.12, respectively.

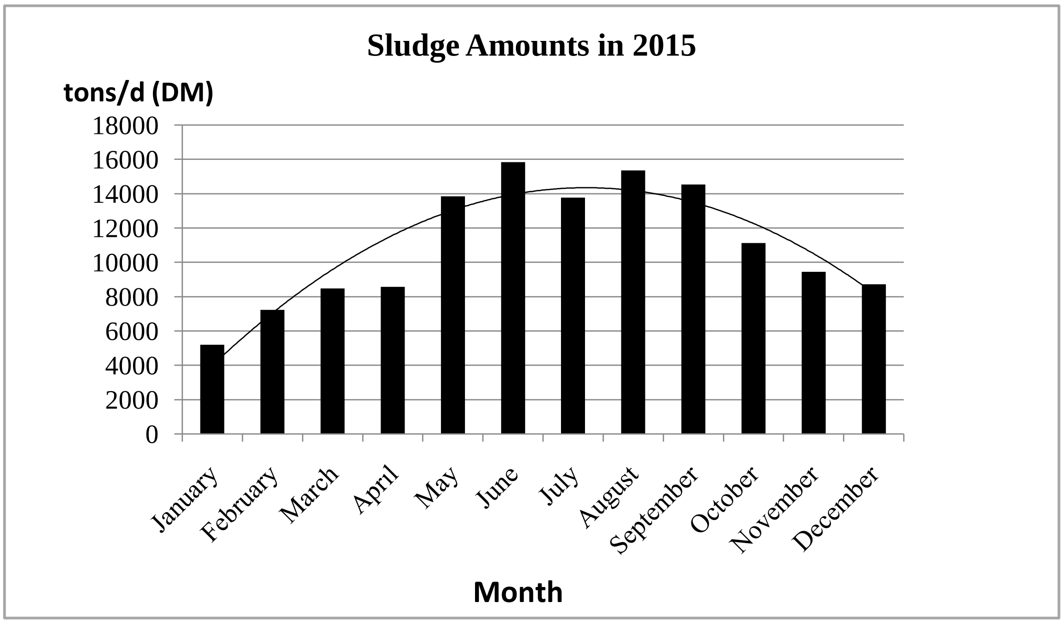

Figure 3.10 Sludge amounts in 2015 by months

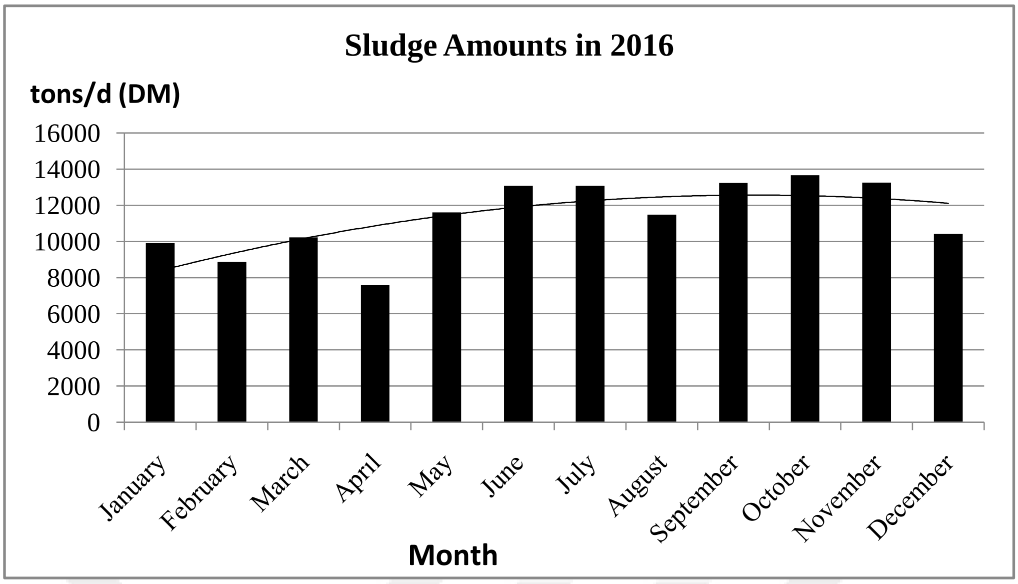

Figure 3.11 Sludge amounts in 2016 by months

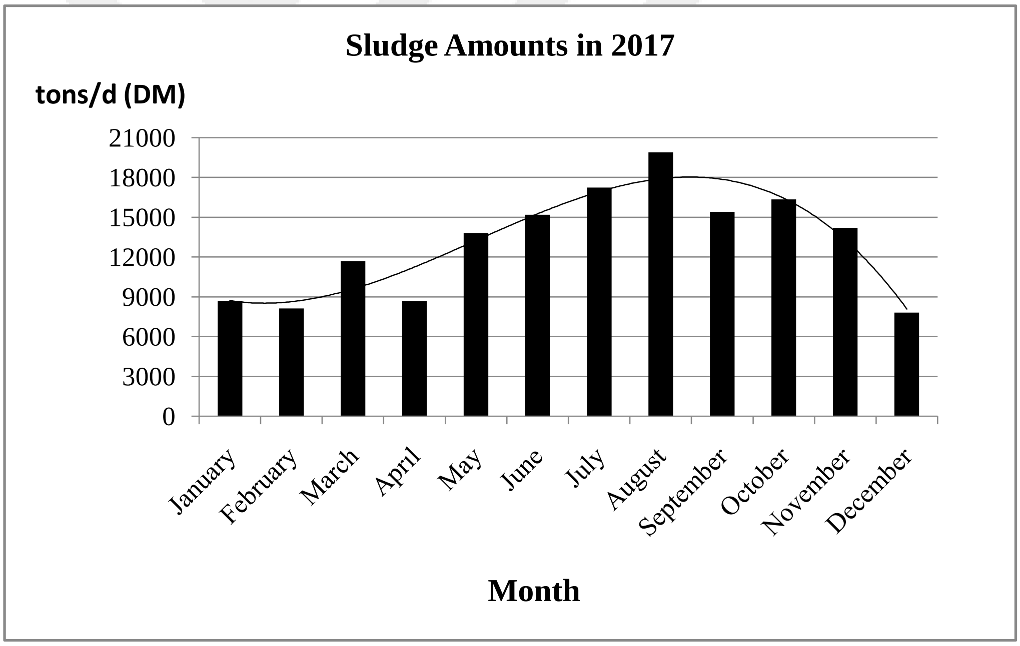

Figure 3.12 Sludge amounts in 2017 by months

The number of tourists visited the city in 2015 and the amount of sludge formed in 2015 was significantly in parallel with each other. Due to the lack of data on the number of tourists, who visited the city in 2016 and 2017, the interpretation with the amount of sludge in these years in parallel with the number of tourists arriving cannot be made. However, the fact that the amount of sludge generated in 2016 has approximate figures in months is considered to be related to the low tourism season in the year in question. In 2017, a linear increase was observed again with the tourism season.

Another problem is that the sludge dewatering units that will provide dewatering in accordance with the conditions of the day are not included in the designing process of wastewater treatment plants. Even today, except in Hurma WWTP, the sludge dewatering process is carried out only with a belt press or decanter. The dry matter content of the sludge generated by these units makes it more difficult to manage sludge. There are various treatment plants established in the tourism areas along the 640 km coastline. However, the construction of such drying plants becomes difficult due to reasons, such as initial investment and operating costs and space requirements.

Although sludge has nutritional elements and rich organic substances, restrictions on the use of sewage sludge as land reclamation and/or fertilizer due to the heavy metal and pathogen content effect asset in the legislation make it difficult to use the sludge in soil, which is considered as one of the most suitable disposal methods in terms of costs.

In Antalya, there are outdoor and indoor vegetable production is made in 50,667 hectares, ornamental plants are produced in 551 hectares, fruits are planted in 74,787 hectares, field crops are produced in 184,867 hectares and commercial plant production is made in 64.7 hectares of the existing 365,248 ha agricultural land. In addition, a meadow/pasture area of 186,000 ha is available (TUİK, 2018). Treatment sludge has not used the soil of the city, which ranks second in the country in terms of agricultural production values according to the Regulation on the Use of Domestic and Municipal Treatment Sludge in Soil published in the Official Gazette dated 03.08.2010 and numbered 27661 (RTMEU, 2018). The main reason for this is considered to be the intensive cultivation of raw fruit and vegetable products within the region. However, since the soil analyzes related to the agricultural areas in the province cannot be accessed, no interpretation can be made as to whether the heavy metal limit values provided in Annex 1-A of the Regulation are met or not.

Since the generated treatment sludge cannot be used in the soil, an alternative method was developed, which can be summarized as drying the sludge and disposal of those in cement plants through the use as additional fuel. Individual private sludge drying plants were established due to the lack of 90% DM content required for additional fuel with the existing sludge dewatering units in WWTPs. Individual drying plants were operated with the Ministry of Environment and Urbanization under the Non-Hazardous Waste Recycling License, of which one had thermal drying and three had solar drying processes. However, licenses for two of these plants were revoked for various reasons, and there are only two plants under operation today.

Under the current circumstances, transportation and dewatering of the sludge to the licensed facilities in Korkuteli and Manavgat, and then delivering the dry sludge to the cement factories and ensuring the disposal of it is considered as the best option.

The problem that we should focus on here is that these plants with a capacity of 235 tons/day and 100 tons/day are barely able to meet the daily total sludge capacity of the whole city together with the Hurma Thermal Drying and Cogeneration Plant which has a capacity of 150 tons/day. For example, if more than 430.8 tons/day of sludge is generated, which is the declared figure for 2017, these plants will be insufficient. In addition, the absence of any cement factory in Antalya and a lime kiln providing final disposal increases the costs of transport and disposal.

Finally, although an undesirable alternative in sludge management, there are three landfills in the city. Kızıllı Solid Waste Landfill, licensed by the Ministry of Environment and Urbanization within the scope of storing sewage sludge, does not accept any sludge into the plant due to problems experienced in operation.

Regarding the management of sludge generated by industrial operation, the sludge does not pose a problem for the city. Organized Industrial Zone, which generates the largest amount of industrial sludge, has a solar drying plant with a capacity of 40 tons/day and other sources of industrial sludge create a trace amount of sludge.

Management of treatment sludge within the framework of the above-mentioned issues is also a problem in Antalya as it is in Turkey. However, considering the contribution of the city to tourism revenues, this becomes more important. According to the facts mentioned here, scenarios have been developed in the fourth chapter by different alternatives for the management of sludge that will be formed in the following years, and the installation and transportation cost and feasibility issues are discussed.

CHAPTER FOUR
RESULTS: SLUDGE MANAGEMENT ALTERNATIVES

4.1 Population Projection

Within the scope of this thesis, sludge amounts were considered for the years of 2017 and 2037. To estimate the amount of sludge that is expected to be produced in domestic/municipal wastewater treatment plants in 2037, population projections were made by using the Ilbank method.

The population projections were made based on the census population data from 2008, 2011, 2014, and 2017 for each district in Antalya. These census population data obtained from the Turkish Statistical Institute (TUIK) are given in Table 4.1.

Table 4.1 The census population data from 2008, 2011, 2014, and 2017 for each district in Antalya

District	**Year**			
	2008	**2011**	**2014**	**2017**
Akseki	15,828	14,358	12,254	10,471
Aksu	57,072	65,303	68,106	69,967
Alanya	233,919	259,787	285,407	299,464
Demre	25,076	25,384	26,059	25,928
Döşemealtı	40,637	44,272	53,554	59,948
Elmalı	38,077	37,901	38,598	38,651
Finike	46,520	46,256	46,853	48,948
Gazipaşa	48,675	48,184	48,561	49,555
Gündoğmuş	9,246	8,451	7,949	7,593
Ibradı	3,979	3,076	2,800	2,646
Kaş	50,786	53,588	55,574	57,123
Kemer	35,639	38,302	41,621	42,568
Kepez	387,904	419,997	470,759	519,966
Konyaaltı	92,126	127,084	145,648	172,920
Korkuteli	49,553	51,051	52,913	53,610
Kumluca	65,109	65,923	66,783	67,942
Manavgat	179,311	193,738	215,526	226,394
Muratpaşa	377,857	431,348	465,927	488,670
Serik	101,961	109,479	117,670	122,032

The rate of population increases expressed as *p* in the Ilbank method and it is calculated by using Equation 1.

$$p = 100\left(\left(\frac{N_y}{N_e}\right)^{\frac{1}{t_y - t_e}} - 1\right) \quad (4.1)$$

where;

N_y: the last population (population of the year of t_y)

N_e: the former population (population of the year of t_e)

p should be between 1 and 3.

If $p < 1$ then $p = 1$

If $p > 3$ then $p = 3$

If $1 < p < 3$ then the calculated *p* is directly used

The future population is calculated by using Equation 2.

$$N_g = N_s * \left(1 + \frac{p}{100}\right)^n \quad (4.2)$$

where;

N_g: the future population

N_s: the last population

$n = t_{future} - t_{last}$

The calculated p values and the population of the year 2037 for each district in Antalya are given in Table 4.2.

Table 4.2 The population of the year 2037

District	p	N 2037
Akseki	-4.5	12,777
Aksu	2.3	110,304
Alanya	2.8	518,842
Demre	0.4	27,931
Döşemealtı	4.4	108,273
Elmalı	0.2	39,962
Finike	0.6	54,832
Gazipaşa	0.2	51,577
Gündoğmuş	-22	9,265
Ibradı	-4.4	3,229
Kaş	1.3	74,191
Kemer	2.0	63,224
Kepez	3.3	939,116
Konyaaltı	7.3	312,313
Korkuteli	0.9	63,861
Kumluca	0.5	74,687
Manavgat	2.6	380,319
Muratpaşa	2.9	866,579
Serik	2.0	181,982
	TOTAL	3,893,264

4.2 Sludge Amounts

4.2.1. Domestic/Municipal Sludge

The amount of domestic/municipal sludge produced in 2017 was obtained from the operational data of the wastewater treatment plants. The domestic/municipal sludge amounts were calculated from the wastewater flowrate, wastewater properties, type of the treatment units, accepted treatment efficiencies, and other assumptions related to kinetic parameters.

The amount of existing sludge production, calculated sludge production of 2017 and estimated future sludge production is given in Table 4.3. The districts served by the treatment plant, capacity and the type of the biological treatment units are also indicated in Table 4.3.

Table 4.3 Sludge amounts for the years of 2017 and 2037

District	WWTP	Capacity	Biological Unit[a]	Sludge Amounts (tons/day)		
				2017 Declared	2017 Calculated	2037
Konyaaltı Kepez Döşemealtı	Hurma	210,000	BP (5-Stage)	181.19	175.1	229.4
Muratpaşa Aksu	Lara	31,250	BP (5-Stage)	46.8	50.0	168.5
Elmalı	Elmalı	2,328	EAAS	3.8	1.9	11.1
Korkuteli	Korkuteli	14,960	EAAS	7.1	12.5	15.3
Kemer	*Beldibi	22,787-55,000	EAAS	4	13.6	45.9
Kemer	*Göynük/ Kızıltepe	16,342-55,000	EAAS	2.6	19.0	
Kemer	Kemer	21,415	EAAS	5.9	17.8	24.0
Kemer	Çamyuva	21,975	EAAS	3.7	18.3	24.6
Kemer	Tekirova	90,00	EAAS	4.7	7.5	10.1
Kumluca	Kumluca	17,300	EAAS	9.4	14.4	14.4
Kumluca	Güzören (Karagöl)	300	EAAS	-	-	-
Kumluca	Karaöz	400	EAAS	-	-	-
Kaş	Kaş	5,400	EAAS	1.8	4.5	9.3
Kaş	Kalkan	4,000	EAAS	0.9	3.3	6.9
Finike	Finike	8,540	MBR	-	-	9.3
Demre	Demre	8,237	EAAS	0.1	6.8	6.8
Serik	*Belek 1	13,100	EAAS	9.7	10.9	-
Serik	*Belek 2	22,600	EAAS	15.3	18.8	-
Serik	Boğazkent	11,000	EAAS	4	9.2	9.2
Serik	Serik-1	25,000	EAAS	8.2	20.9	75.1
Serik	Serik-2	65,000	EAAS	-	-	
Manavgat	Çolaklı	15,000	EAAS	8.1	12.5	15.8
Manavgat	Kumköy	50,000	EAAS	25.4	10.4	13.2
Manavgat	Titreyengöl	10,725	EAAS	4.6	8.9	11.3
Manavgat	Manavgat	100,000	EAAS	28.8	83.4	105.1
Manavgat	Çandır	200	EAAS	-	-	-

Table 4.3 continues

District	WWTP	Capacity	Biological Unit[a]	Sludge Amounts (tons/day)		
Alanya	İncekum (Avsallar)	15,000	EAAS	6.6	12.5	23.9
	Türkler	15,000	EAAS	3.4	12.5	23.9
	Okurcalar	20,000	EAAS	4.5	16.7	31.9
	Konaklı	30,000	EAAS	8	25.0	47.9
	Alanya	70,000	AS+ SBR	10.1	58.4	111.8
	Oba/Tosmur /Cikcilli	31,000	EAAS	8.1	25.9	49.5
	Mahmutlar	20,000	EAAS	12.3	16.7	31.9
Gazipaşa	Gazipaşa	8,800	MBR	1.7	7.1	10.2
Akseki	Akseki	500	EAAS	-	-	2.5
İbradı	İbradı	550	EAAS	-	-	0.9
Gündoğmuş	Gündoğmuş	400	MBR	-	-	1.8
TOTAL				430.8	701.6	1141.4

[a]BP: Bardenpho; EAAS: Extended Aeration Activated Sludge; MBR: Membrane bioreactor; AS+SBR: Activated Sludge + Sequencing Batch Reactor

Calculations indicate that depending on the tourism sector, the tourism accommodation facilities are very intense and 2037 flow rates regarding the wastewater treatment plants located in districts such as Serik, Manavgat, Alanya, and Kemer, meet the current capacities of these facilities. However, since it would not be a realistic approach to ignore domestic wastewater flow rates generated by tourists in these regions, the ratio between the equivalent population served by the plants and the existing population is reflected in the year 2037 and sludge calculations were made accordingly.

As a result of the increase of tourism activity in Beldibi and Göynük regions of Kemer, there has been a significant increase in the population of the region and the existing wastewater treatment plants are challenged for serving the basin flowrate. Therefore, the separately operated wastewater plants in Göynük and Beldibi are planned to be handled together and the wastewater is planned to be disposed of after treated in a single wastewater treatment plant. Within this context, a new wastewater treatment plant with an average flow capacity of 55,000 m^3/day is planned to be constructed, which will serve a population equivalent to 86,088 people to cover Beldibi and Göynük in a new area independent from the old plants. The amount of sludge of Beldibi and Göynük/Kızıltepe WWTPs mentioned in the year 2037 is provided together in the table.

In Serik, especially in the Belek region, where tourism accommodation facilities are intense and therefore high flowrate of wastewater formation is witnessed in summer months, the wastewater is treated in Belek 1 and Belek 2 wastewater treatment plants. Depending on the increase in tourism, seasonal wastewater flow to the plants has increased and the capacities of Belek 1 and Belek 2 wastewater treatment plants became insufficient. At present, the capacity of the Serik1 WWTP is 25,000 m^3/day and domestic wastewater originating in the district is treated here. For this reason, the sludge amounts of Belek 1 and Belek 2 WWTPs in 2037 are not calculated and the total sludge amount of Serik1 and Serik 2 WWTP was calculated in the table.

Under the current circumstances, wastewater treatment plants of Akseki and Ibradı districts are under construction and the plant constructions of Finike and Gündoğmuş districts have been completed but sewage connections to the plant have not been completed; therefore, only the calculated treatment sludge amounts of the plants for 2037 are included in the table.

Since Karaöz, Güzören (Karagöl) and Candır plants are constructed as package treatment plants, there is sludge formation present and the sludge is delivered to the nearest domestic/municipal wastewater treatment plant via sewage trucks. It is foreseen that there will be no capacity increase due to the fact that current plant capacities meet the flow rates calculated for 2037 and it is considered that the sludge disposal will be similar in 2037. Therefore, the table does not include sludge quantity information for 2017 and 2037.

In the table, we see that a total of 430.8 tons/day (DM) sludge formation was declared for 2017; however, this value was calculated as 701.6 tons/day (DM) for 2017. Figure 4.1 is prepared in order to compare the declared and calculated values.

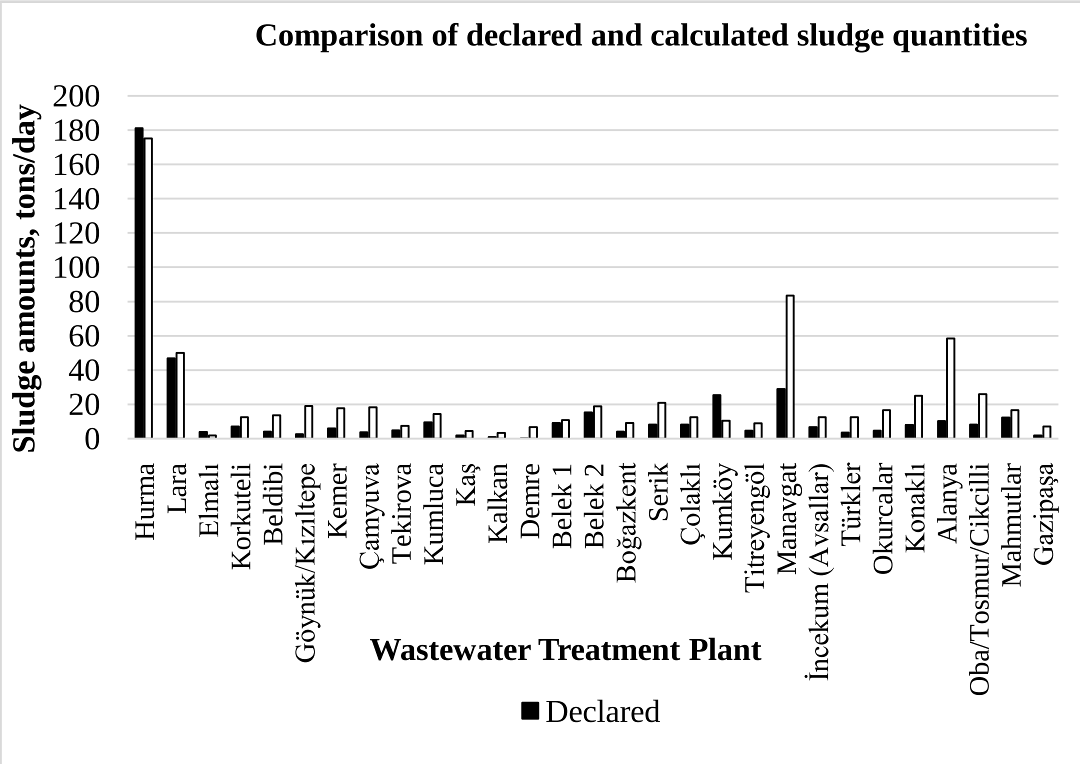

Figure 4.1 Correlation between the declared and calculated sludge amounts

As it can be seen in Figure 4.1, the sludge amount calculated by considering the existing flow rates of wastewater treatment plants and the declared sludge amounts is similar in most plants. However, it is also seen that the amount of sludge declared in 2017 is below the values calculated in 2017 in the treatment plants built with high capacity. The reason for this may be the fact that the winter sludge generated in these plants that operate well below their current capacity during winter, has an impact on the decrease of the annual average.

There is a significant difference between the total amount of declared and calculated sludge amounts. However, almost similar results were obtained in some plants, such as Hurma and Lara Advanced WWTP. The comparison of these amounts is given in Figure 4.1. This difference may be from the misinformation or from some assumptions made for the calculation. Nevertheless, the correlation coefficient (R^2 = 0,84) shows that there is a significant linear relationship between the declared and calculated sludge amounts (Figure 4.2).

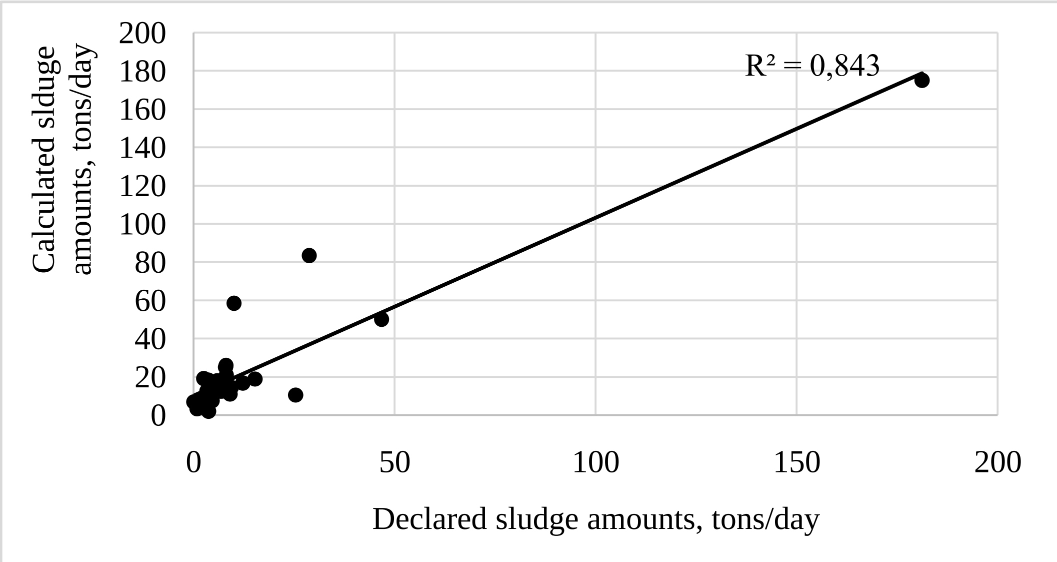

Figure 4.2 Comparison of declared and calculated sludge quantities

In the previous chapters, Table 3.2 provides flow information for individual domestic wastewater treatments. Most of these plants are designed as package treatment plants. Due to the low capacity of the plants built with this purpose, the sludge formation is in small amounts and as the sludge dewatering process requires extra cost, the sludge formed as a result of sedimentation in the plants is delivered to the nearest municipal/domestic wastewater treatment plant. When we take the capacities of other municipal/domestic wastewater treatment plants into consideration, it is assumed that the contribution of individual domestic treatments to the sludge amount in the province is scarce and that the sludge amounts of these plants will not change in the year 2037.

4.2.2 Industrial Sludge

Currently, 20,000 m^3/day capacity wastewater treatment plant in Antalya Organized Industrial Zone forms 20-25 tons/day industrial sludge with 20-25 % DM content. The sludge is dried in the greenhouse type solar drying plant integrated with the wastewater treatment plant of the organized industrial zone and delivered to the cement plants to be used as additional fuel with 85% DM content. Assuming that the development of the industry will contribute about 10% to the amount of industrial sludge in the coming years, the amount of industrial sludge in 2037 is calculated as 27.5 tons/day (DM).

As can be seen in Table 3.3 in the previous chapter, the capacities of the individual industrial plants are quite low. The currently formed hazardous treatment sludge is delivered to licensed disposal plants. The sludge formed in other plants is delivered to the nearest municipal wastewater treatment plant via sewage trucks and disposed of accordingly.

Although the formation of sludge is very low in these plants, it is assumed that the capacities of plants will not change in 2037 and the industrial sludge formed in individual plants is neglected in calculations.

4.3 Sludge Disposal and Recovery Plants

Regarding the management of treatment sludge in the city, the Ministry of Environment and Urbanization operates three plants with a non-hazardous waste recovery license and one plant with a landfill license.

However, Kalemirler Biogas Plant and Kızıllı Solid Waste Landfill do not accept sludge into their processes due to the problems in operation. There are no incineration plants, cement plants and/or lime kiln in the city, neither there are any gasification and pyrolysis plants. The sludges dried in thermal/solar drying plants are delivered for disposal as additional fuel to the cement plants operating in nearby provinces.

Licensed Mer-su Solar and Thermal Drying Plant aim to incinerate sludge by adding an incineration plant to its units.

In Figure 4.3, the plants within the city and the cement factories in the surrounding provinces are shown on the map and the information about the plants is summarized below.

Table 4.4 Sludge drying and final disposal plants in Antalya

Plant	Capacity
Hurma Thermal Drying and Cogeneration Plant	150 tons/d
Baturalp Solar Drying	235 tons/d
Mer-su Solar/Thermal Drying Plant	100 tons/d solar drying 95 tons/d thermal drying
Kızıllı Solid Waste Landfill	Sludge is not accepted.
Kalemirler Biogas Plant	Sludge is not accepted.
AS Cement Plant (Burdur)	100 tons/d
Denizli Cement Plant (Denizli)	10 tons/d
Konya Cement Plant (Konya)	No information
Antalya Organized Industrial Zone Solar Drying Plant	40 tons/d

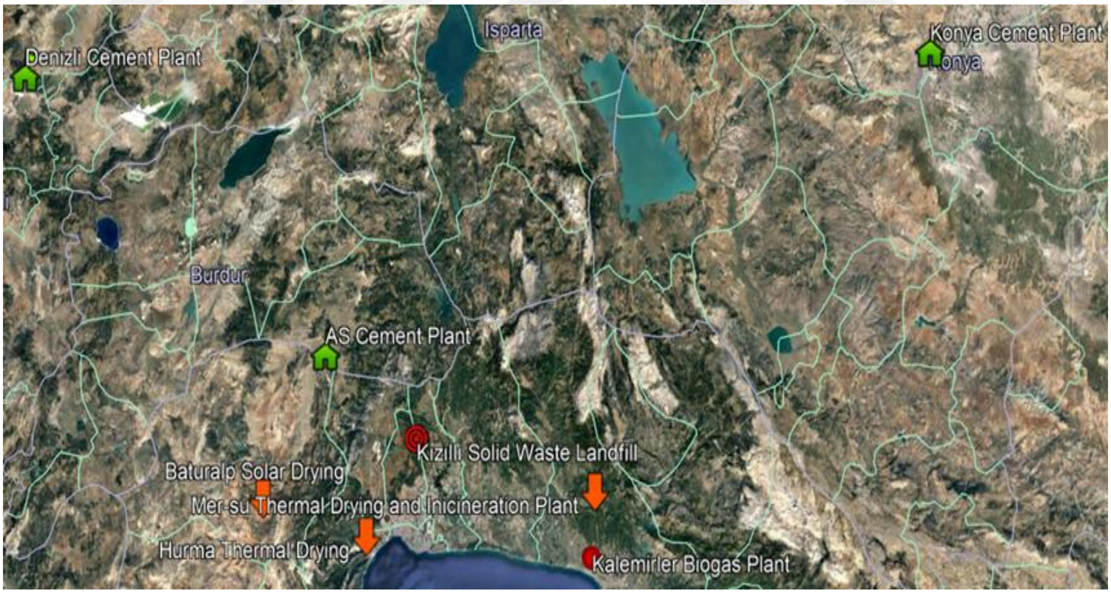

Figure 4.3 Existing drying and disposal plants (adapted from Google Earth, 2019)

4.3.1 Hurma WWTP Thermal Drying and Cogeneration Plant

Hurma Thermal Drying and Cogeneration Plant, which was established as an integrated part of the treatment plant within the field of Hurma Wastewater Treatment Plant, was put into operation in June 2008. In the planning stage of the plant, by taking into consideration of the fact that approximately 100 tons/d of sludge with 16-20 % DM content in the Hurma Wastewater Treatment Plant and 50 tons/d of sludge with 22-24% DM content in the Lara Wastewater Treatment Plant is formed, the drying plant is designed to dry the sludge from both plants by 150 tons/day capacity. However, since the amount of sludge generated in the Hurma Wastewater Treatment Plant is over 150 tons/day, the thermal drying and cogeneration plant serves only to Hurma WWTP. The flow diagram of the drying plant is given in Figure 4.4.

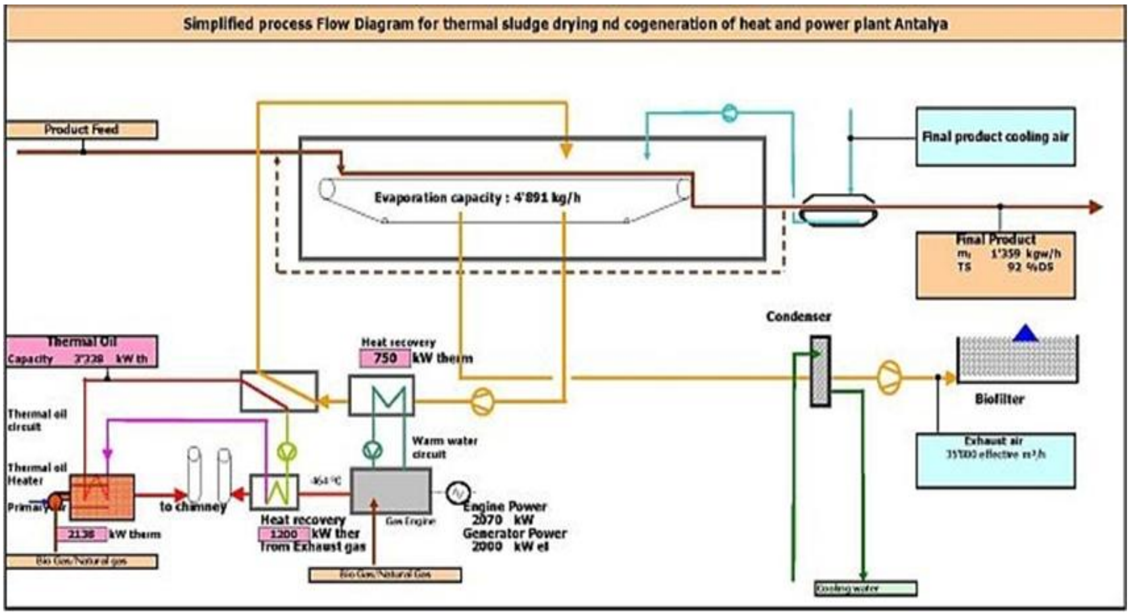

Figure 4.4 Hurma thermal drying and cogeneration plant process (ASAT, 2019)

The plant is designed to benefit from the waste heat generated during the energy production for the needs of the wastewater treatment plant and the drying plant. Some information about the plant is given in Table 4.5.

Table 4.5 Hurma treatment sludge thermal drying and cogeneration plant features

Amount of Dewatered Sludge	6,250 kg/h
Water Evaporation	4,891 kg/h
Dry Product	1,359 kg/h (dryness>90)
Type of Dryer	Belt dryer

All of the above information is obtained from the official website of ASAT. The information about the following plants was obtained from the Antalya Provincial Directorate of Environment and Urbanization.

4.3.2 Mer-su Solar/Thermal Drying Plant

Domestic sludge solar and thermal drying facility, which owns the Ministry of Environment and Urbanization Non-Hazardous Waste Recovery License, is operating in the Manavgat district. The capacity of the solar drying plant is 100 tons/day (DM) and it consists of seven greenhouse-type solar drying beds with a 10x6 m impermeable concrete floor. The sludge delivered to solar drying with 10% DM content leaves the plant with 40% DM content. There is also a coal-fired rotary type thermal drying plant with a capacity of 90 tons/day. The sludge delivered to the thermal drying plant with a content of 40% DM is dried with a content of 70-90 % DM. In order to reduce the fuel costs of thermal drying, the dried treatment sludge is planned to be burned, and the related work for this is still being done.

4.3.3 Baturalp Solar Drying

Solar drying plant with the Ministry of Environment and Urbanization Hazardous Waste Recovery License has 235 tons/day capacity and operates in Korkuteli District. The treatment sludge that enters the plant with a moisture content of 80-90%, gets 75% DM content after drying. There are three greenhouse type solar dryers built in parallel to each other in the dimensions of 10x150.

4.3.4 Kızıllı Integrated Waste Evaluation, Recycling and Disposal Plant

Kızıllı Integrated Waste Evaluation, Recycling, and Disposal Plant consist of mechanical separation plants, biomethanization plants, compost plant, and class II regular storage area and of energy production facilities, medical waste sterilization plant, waste battery temporary storage area. Approximately 800 tons of solid waste is disposed of in an appropriate manner in the plant operating in the Kepez district and 20 MW of electricity is generated in the power generation facility. However, due to the problems in the operation, the plant does not accept treatment sludge.

4.3.5 Kalemirler Biogas Plant

The plant has a Non-Hazardous Waste Recovery License from the Ministry of Environment and Urbanization and it is planned for biogas generation from animal waste and operates with 556 tons of waste capacity per day. The plant is located in Manavgat district, but treatment sludge cannot be accepted due to its negative impact on the process.

4.3.6 Organized Industrial Zone Solar Sludge Drying Plant

In the selection of drying technology of organized industrial sludge, which is considered hazardous waste, solar drying was preferred due to the conditions of the region, low energy, and operating costs. In the wastewater treatment plant, sludge from the dehydrator with a solid content of 40-50% is delivered for solar drying. Solar Drying Plant consists of 1 greenhouse and has a processing capacity of 40 tons/day sludge cake with a 20% DM rate. There is a drum mixer, axial and exhaust fans in the greenhouse. The fans operate automatically depending on the internal and external humidity values received from the climate station in the plant. Considering that solar radiation may be insufficient in the greenhouse, a natural gas-powered sub-heating system has also been added for use in winter. Treatment sludges with a dryness level of 85% or more are delivered to cement plants as additional fuel and disposed of. The layout of the facility is shown in Figure 4.5.

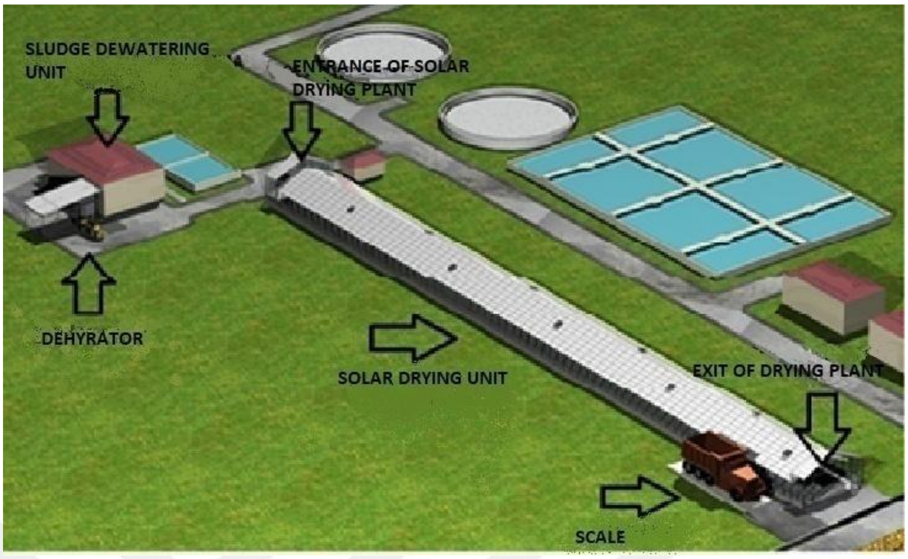

Figure 4.5 Antalya organized industry zone solar drying plant layout plan (Antalya organized industry zone, n.d.)

4.4 Recommended Sludge Removal Techniques

Within the scope of the study, three scenarios were developed by taking into consideration the locations, capacities and transportation distances of the plants, where treatment sludges are formed and the disposal plants.

In order to reduce the investment costs, the scenarios were based on individual private plants and infrastructure management plants, which are licensed by the Ministry of Environment and Urbanization regarding infrastructure management (ASAT), and capacity and investment cost calculations were made based on these plants. The investment costs of the plants planned to be built/capacity to be increased were calculated by adapting the investment costs compiled from different projects of similar plants to the scenarios.

In the drying plants where the infrastructure management has disposed of sludge, the disposal cost has been tendered as 200 ₺/ton; this cost was used in the calculation of sludge disposal cost in solar drying. Mer-su Solar/Thermal Drying Plant, which plans to add an incineration plant, will have been determined the disposal cost with incineration will be 250 ₺ per ton and calculations are made by using this price.

After thermal drying, it is foreseen that sludges containing 90% DM content will be delivered to cement plants as additional fuel and disposed of accordingly. In the calculations, 250 ₺/ton was used as the disposal cost per ton in cement plants.

The transportation costs were calculated on the assumption that transportation will be carried out via trucks with a capacity of 24 tons. The fuel consumption for the 24-ton truck is 0.32 L/km. The expenses such as tire, maintenance and repair, and personnel are reflected in the annual transportation costs with the assumption that they consist of 40% of the transportation cost (Gül & Elevli,2006). For the transportation cost calculations, the price of diesel liters dated 04.03.2019 for Antalya as 6.52 ₺ was used.

In the scenarios, it was envisaged that 75% DM sludge, which may occur as a result of solar drying, will be used for agricultural purposes within the framework of the Regulation on the Use of Domestic and Municipal Treatment Sludges in Soil. The maximum treatment sludge application dose was considered as 1-ton dry matter/da as set out in TÜBİTAKKAMAG1007-Domestic/MunicipalTreatment Sludge Management Project. Information on cultivated areas that can be used for this purpose is given in Table 4.6.

When the scenarios were developed, because Baturalp Solar Drying Plant is located in the Korkuteli district, the dry sludge formed in the mentioned plant is planned to be used in fodder and commercial cultivated areas with a total of 334,097 da. However, since the areas in which these cultivations are made were not included in the scope of this study, transportation cost calculations were made according to the nearest agricultural land.

Table 4.6 2018 districts fodder and cultivated area (TUİK, 2018)

District	Fodder Field (da)	Cotton Field (da)
Akseki	3,202	
Aksu	4,194	13,988
Alanya	4,367	
Demre	2,683	
Döşemealtı	2,6917	7
Elmalı	105,758	
Finike	2,732	
Gazipaşa	4,911	
Gündoğmuş	1,969	
İbradı	4,178	
Kaş	11,630	
Kemer	28	
Kepez	5,024	
Konyaaltı	139	
Korkuteli	334,097	
Kumluca	3,024	
Manavgat	25,363	11,519
Muratpaşa		51
Serik	6,667	24,189
TOTAL	546,883	25,565

It was planned to use dry sludge in Elmalı, which is the nearest district, where the limit value can be provided if the annual amount of dry sludge formed in Kumluca Solar Drying Facility, as foreseen to be established in accordance with Scenario 1 and 3, is not used in the agricultural areas located in Kumluca. However, since the land, which was cultivated for fodder and/or commercial purposes, was not included in the scope of the study, the nearest agricultural land to the drying facility was determined and transportation cost calculations were made accordingly.

While the scenarios created, it is predicted that the total dry sludge produced annually in agricultural usage of sludge will be applied to the soil once a year. Due to the large scale application areas, it was calculated that very low amounts of sludge would be applied per decare. However, it is important to apply approximately 1 ton of sludge per agricultural use in order to be efficient. For this reason, it is useful to make the application in the narrower areas than the mentioned areas provided that they do not exceed the mentioned value.

Disposal costs were not calculated for the use of sludge in the soil in the disposal/transportation cost calculations. For the disposal/transportation cost calculations, euro rate of the Central Bank of the Republic of Turkey's dated 04.03.2019 was 6.11 ₺. In the scenarios developed, the costs of the new plants and the operating costs including the transportation/disposal costs are given in Table 4.7 - 4.12.

Table 4.7 Investment costs for Scenario 1

DISTRICT	WWTP	Sludge Amount in 2017	Disposal Plant	Disposal Plant's Existing Capacity	Disposal Plant's New Capacity	Disposal Plant Construction Cost	Plant Output
KONYAALTI	HURMA	229.4	Hurma Thermal Drying and Cogeneration Plant	150 tons/day	350 tons/day capacity increase resulted in a total of 500 tons/day	8,200,000 € thermal drying 1,300,000 € anaerobic digester total 9,500,000 €	100 tons/day AS Cement Plant/Will be delivered to BURDUR in order to be incarcerated as additional fuel
KEPEZ							
DÖŞEMEALTI							
MURATPAŞA	LARA	168.5					
AKSU							
KEMER	Beldibi	45.9					Will be delivered to 40 tons/day Mer-su Solar-thermal Drying and Incineration Plant for disposal.
	KEMER	24.0					
	Çamyuva	24.6					
	Tekirova	10.1					
KUMLUCA	KUMLUCA	14.4	Kumluca Solar Drying Plant	-	40 tons/day	2,000,000 €	Dry sludge that is generated throughout the year with 75 % KM content Which is 4,870 tons will be delivered to Agricultural land cultivated for fodder plants in an area of 105,728 da and will be disposed of. and the application will be done as 0.05 tons/da.
KAŞ	KAŞ	9.3					
	Kalkan	6.9					
FİNİKE	FİNİKE	9.3					
DEMRE	DEMRE	6.8					
SERİK	Boğazkent	9.2	Mer-su Solar-Thermal Drying and Incineration Plant	100 tons/say solar drying 95 tons/day thermal drying-Incineration	355 tons/day Increase resulting in 450 tons/day thermal drying 70 tons/day capacity increase resulting with 165 tons/day inciniration plant	9,320,000 € thermal drying 4,340,00 € Incineration plant cost total 13,660,000 €	-
	SERİK 1	20.9					
	SERİK 2	54.2					
MANAVGAT	Çolaklı	15.8					
	Kumköy	13.2					
	Titreyengöl	11.3					
	MANAVGAT	105.1					
ALANYA	İncekum (Avsallar)	23.9					
	Türkler	23.9					
	Okurcalar	31.9					
	Konaklı	47.9					
	ALANYA	111.8					
	Oba/Tosmur/ Cikcilli	49.5					
	Mahmutlar	31.9					
GAZİPAŞA	GAZİPAŞA	10.2					
AKSEKİ	AKSEKİ	2.5					
İBRADI	İBRADI	0.9					
GÜNDOĞMUŞ	GÜNDOĞMUŞ	1.8					
ELMALI	ELMALI	11.1	Baturalp Solar Drying Plant	235 tons/day	-	-	Dry sludge that is generated throughout the year with 75 % KM content Which is 2,740 tons will be delivered to Agricultural land cultivated for fodder plants in an area of 334,097 da at Korkuteli and will be disposed of. and the application will be done as 0.008 tons/da.
KORKUTELİ	KORKUTELİ	15.3					
					TOTAL	25,160,000 €	

Table 4.8 Transportation and disposal costs for scenario 1

<table>
<tr><th>WWTP</th><th>Distance Between WWTP-Drying Plant</th><th>Annual transportation cost with 40 % maintenance cost</th><th>Disposal Plant where Sludge is Delivered to</th><th>Annual Drying Cost</th><th>Final Disposal</th><th>Distance between Drying-Final Disposal (km)</th><th>Annual transportation cost with 40 % maintenance cost</th><th>Disposal Cost</th></tr>
<tr><td>HURMA</td><td>-</td><td>-</td><td rowspan="6">Hurma Thermal Drying and Cogeneration Plant</td><td rowspan="6">It belongs to ASAT. therefore drying cost is not determined.</td><td rowspan="2">AS Cement Plant</td><td rowspan="2">68.3</td><td rowspan="2">291,272 ₺</td><td rowspan="2">9.125.000 ₺</td></tr>
<tr><td>LARA</td><td>36.2</td><td>212,271 ₺</td></tr>
<tr><td>BELDIBI</td><td>17.6</td><td>37,528 ₺</td><td rowspan="4">Mer-su Solar-Thermal Drying and Incineration Plant</td><td rowspan="4">89.0</td><td rowspan="4">151,820 ₺</td><td rowspan="4">3.650.000 ₺</td></tr>
<tr><td>KEMER</td><td>33.1</td><td>35,290 ₺</td></tr>
<tr><td>ÇAMYUVA</td><td>39.2</td><td>41,793 ₺</td></tr>
<tr><td>TEKIROVA</td><td>49</td><td>17,414 ₺</td></tr>
<tr><td>KUMLUCA</td><td>-</td><td>0</td><td rowspan="5">Kumluca Solar Drying Plant</td><td rowspan="5">It belongs to ASAT. therefore disposal cost is not determined.</td><td rowspan="5">Use on Soil</td><td rowspan="5">64.0</td><td rowspan="5">40,940 ₺</td><td rowspan="5">-</td></tr>
<tr><td>KAŞ</td><td>93.2</td><td>30,165 ₺</td></tr>
<tr><td>KALKAN</td><td>110</td><td>26,384 ₺</td></tr>
<tr><td>FINIKE</td><td>16.3</td><td>5,240 ₺</td></tr>
<tr><td>DEMRE</td><td>40.5</td><td>9,597 ₺</td></tr>
<tr><td>BOĞAZKENT</td><td>43.1</td><td>11,488 ₺</td><td rowspan="18">Mer-su Solar-Thermal Drying and Incineration Plant</td><td rowspan="18">-</td><td rowspan="18">-</td><td rowspan="18">-</td><td rowspan="18">-</td><td rowspan="18">40.277.750 ₺</td></tr>
<tr><td>SERIK 1</td><td rowspan="2">39.6</td><td rowspan="2">126,659 ₺</td></tr>
<tr><td>SERIK 2</td></tr>
<tr><td>ÇOLAKLI</td><td>25</td><td>13,327 ₺</td></tr>
<tr><td>KUMKÖY</td><td>24.9</td><td>13,274 ₺</td></tr>
<tr><td>TITREYENGÖL</td><td>29.9</td><td>10,626 ₺</td></tr>
<tr><td>MANAVGAT</td><td>30.8</td><td>131,350 ₺</td></tr>
<tr><td>İNCEKUM (AVSALLAR)</td><td>59</td><td>62,903 ₺</td></tr>
<tr><td>TÜRKLER</td><td>68.2</td><td>72,711 ₺</td></tr>
<tr><td>OKURCALAR</td><td>50</td><td>53,308 ₺</td></tr>
<tr><td>KONAKLI</td><td>76.2</td><td>162,481 ₺</td></tr>
<tr><td>ALANYA</td><td>82.6</td><td>352,256 ₺</td></tr>
<tr><td>OBA/TOSMUR/ CIKCILLI</td><td>91.2</td><td>194,466 ₺</td></tr>
<tr><td>MAHMUTLAR</td><td>97.1</td><td>103,523 ₺</td></tr>
<tr><td>GAZIPAŞA</td><td>131</td><td>46,510 ₺</td></tr>
<tr><td>AKSEKI</td><td>102</td><td>9,531 ₺</td></tr>
<tr><td>IBRADI</td><td>37.8</td><td>1,141 ₺</td></tr>
<tr><td>GÜNDOĞMUŞ</td><td>95.7</td><td>6,099 ₺</td></tr>
<tr><td>ELMALI</td><td>59.8</td><td>24,440 ₺</td><td rowspan="2">Baturalp Solar Drying Plant</td><td rowspan="2">1,598,700 ₺</td><td rowspan="2">Use on Soil</td><td rowspan="2">1.0</td><td rowspan="2">341 ₺</td><td rowspan="2">-</td></tr>
<tr><td>KORKUTELI</td><td>13.8</td><td>7,808 ₺</td></tr>
<tr><td colspan="2">TOTAL</td><td>1,819,582 ₺</td><td></td><td>1,598,700 ₺</td><td colspan="2"></td><td>484.373 ₺</td><td>53,052,750 ₺</td></tr>
</table>

Table 4.9 Investment costs for Scenario 2

DISTRICT	WWTP	Sludge Amount in 2037	Disposal Plant	Disposal Plant's Existing Capacity	Disposal Plant's New Capacity	Disposal Plant Construction Cost	Plant Output
KONYAALTI	HURMA	229.4	Hurma Thermal Drying and Cogeneration Plant	150 tons/day	200 tons/day capacity increase resulted in a total of 350 tons/day	4,720,000 € thermal drying 765,000 € anaerobic digesters total 5,485,000 €	All of the dry sludge will be delivered to AS Cement Plant / BURDUR as additional fuel for disposal.
KEPEZ							
DÖŞEMEALTI							
KEMER	Beldibi	45.9					
	KEMER	24.0					
	Çamyuva	24.6					
	Tekirova	10.1					
SERİK	Boğazkent	9.2	Mer-su Solar-Thermal Drying and Incineration Plant	100 tons/day solar drying 95 tons/day thermal drying Incineration	355 tons/day capacity increase resulted in a total of 450 tons/day	9,320,000 € thermal drying	95 tons/day of the generated 125 tons/day dry sludge will be disposed of in the existing incineration plant. 30 tons/day dry sludge which cannot be delivered to the incineration plant will be delivered to Konya Cement Plant and will be disposed of as additional fuel.
	SERİK 1	20.9					
	SERİK 2	54.2					
MANAVGAT	Çolaklı	15.8					
	Kumköy	13.2					
	Titreyengöl	11.3					
	MANAVGAT	105.1					
ALANYA	İncekum (Avsallar)	23.9					
	Türkler	23.9					
	Okurcalar	31.9					
	Konaklı	47.9					
	ALANYA	111.8					
	Oba/Tosmur/Cikcilli	49.5					
	Mahmutlar	31.9					
GAZİPAŞA	GAZİPAŞA	10.2					
AKSEKİ	AKSEKİ	2.5					
İBRADI	İBRADI	0.9					
GÜNDOĞMUŞ	GÜNDOĞMUŞ	1.8					
ELMALI	ELMALI	11.1	Baturalp Solar Drying Plant	235 tons/day	-	-	Dry sludge that is generated throughout the year with 75 % KM content Which is 23,725 tons will be delivered to Agricultural land cultivated for fodder plants in an area of 334,097 da at Korkuteli and will be disposed. and the application will be done as 0.007 tons/da.
KORKUTELİ	KORKUTELİ	15.3					
MURATPAŞA-AKSU	LARA	168.5					
KUMLUCA	KUMLUCA	14.4					
FİNİKE	FİNİKE	9.3					
DEMRE	DEMRE	6.8					
KAŞ	KAŞ	9.3					
	Kalkan	6.9					
					TOTAL	14,805,000 €	

Table 4.10 Transportation and disposal costs for scenario 2

WWTP	Distance Between WWTP-Drying Plant	Annual transportation cost with 40 % maintenance cost	Disposal Plant where Sludge is Delivered to	Annual Drying Cost	Final Disposal	Distance between Drying-Final Disposal (km)	Annual transportation cost with 40 % maintenance cost	Disposal Cost
HURMA			Hurma Thermal Drying and Cogeneration Plant	It belongs to ASAT; therefore. disposal cost is not determined.	AS Cement Plant	68.3	291,272 ₺	9.125.000 ₺
BELDIBI	17,6	37,528 ₺						
KEMER	33,1	35,290 ₺						
ÇAMYUVA	39,2	41,793 ₺						
TEKIROVA	49	17,414 ₺						
BOĞAZKENT	43,1	11,488 ₺	Mer-su Solar-Thermal Drying and Incineration Plant	-	For the part delivered to Konya Cement Plant	264	333,756 ₺	2.737.500 ₺
SERIK 1	39,6	126,659 ₺						
SERIK 2								
ÇOLAKLI	25	13,327 ₺						
KUMKÖY	24,9	13,274 ₺						
TITREYENGÖL	29,9	10,626 ₺						
MANAVGAT	30,8	131,350 ₺						
İNCEKUM (AVSALLAR)	59	62,903 ₺						
TÜRKLER	68,2	72,711 ₺						
OKURCALAR	50	53,308 ₺			-	-	-	40.277.750 ₺
KONAKLI	76,2	162,481 ₺						
ALANYA	82,6	352,256 ₺						
OBA/TOSMUR/ CIKCILLI	91,2	194,466 ₺						
MAHMUTLAR	97,1	103,523 ₺						
GAZIPAŞA	131	46,510 ₺						
AKSEKI	102	9,531 ₺						
IBRADI	37,8	1,141 ₺						
GÜNDOĞMUŞ	95,7	6,099 ₺						
ELMALI	59,8	24,440 ₺	Baturalp Solar Drying Plant	13.862.700 ₺	Use on Soil	1	2,695 ₺	-
KORKUTELI	13,8	7,808 ₺						
LARA	91,8	538,299 ₺						
KUMLUCA	131	65,492 ₺						
FINIKE	120	38,579 ₺						
DEMRE	147	34,834 ₺						
KAŞ	158	51,138 ₺						
KALKAN	174	46,378 ₺						
	TOTAL	2,310,644 ₺		13,862,700 ₺			627.723 ₺	52,140,250 ₺

Table 4.11 Investment costs for Scenario 3

DISTRICT	WWTP	Sludge Amount in 2037	Disposal Plant	Disposal Plant's Existing Capacity	Disposal Plant's New Capacity	Disposal Plant Construction Cost	Plant Output
KONYAALTI	HURMA	229.4	Hurma Thermal Drying and Cogeneration Plant	150 tons/day	-	-	Approximately 80 tons/day capacity sludge which cannot be delivered to thermal drying will be delivered to Baturalp Solar Drying Plant and disposed of accordingly.
KEPEZ							
DÖŞEMEALTI							Dry sludge from thermal drying with approximately 42 tons/day capacity will be delivered to AS Cement Plant/ BURDUR and will be disposed of as additional fuel.
MURATPAŞA	LARA	168.5	Baturalp Solar Drying Plant	235 tons/day	-	-	Dry sludge that is generated throughout the year with 75 % KM content Which is 29,200 tons will be delivered to Agricultural land cultivated for fodder plants in an area of 105,728 da at Korkuteli and will be disposed of. and the application will be done as 0.09 tons/da.
AKSU							
ELMALI	ELMALI	11.1					
KORKUTELİ	KORKUTELİ	15.3					
KEMER	Beldibi	45.9	Kumluca Solar Drying Plant	-	120 tons/day	5,350,000 €	Dry sludge that is generated throughout the year with 75 % KM content Which is 14,600 tons will be delivered to Agricultural land cultivated for fodder plants in an area of 334,097 da at Korkuteli and will be disposed of. and the application will be done as 0.14 tons/da.
	KEMER	24.0					
	Çamyuva	24.6					
	Tekirova	10.1					
KUMLUCA	KUMLUCA	14.4					
KAŞ	KAŞ	9.3					
	Kalkan	6.9					
FİNİKE	FİNİKE	9.3					
DEMRE	DEMRE	6.8					
SERİK	Boğazkent	9.2	Mer-su Solar-Thermal Drying and Incineration Plant	100 tons/day solar drying 95 tons/day thermal drying-Incineration	355 tons/day capacity increase resulted in a total of 450 tons/day	9,320,000 € thermal drying	95 tons/day of the generated 125 tons/day dry sludge will be disposed of in the existing incineration plant. 30 tons/day dry sludge which cannot be delivered to the incineration plant will be delivered to AS Cement Plant and will be disposed of as additional fuel.
	SERİK 1	20.9					
	SERİK 2	54.2					
MANAVGAT	Çolaklı	15.8					
	Kumköy	13.2					
	Titreyengöl	11.3					
	MANAVGAT	105.1					
ALANYA	İncekum (Avsallar)	23.9					
	Türkler	23.9					
	Okurcalar	31.9					
	Konaklı	47.9					
	ALANYA	111.8					
	Oba/Tosmur/ Cikcilli	49.5					
	Mahmutlar	31.9					
GAZİPAŞA	GAZİPAŞA	10.2					
AKSEKİ	AKSEKİ	2.5					
İBRADI	İBRADI	0.9					
GÜNDOĞMUŞ	GÜNDOĞMUŞ	1.8					
					TOTAL	14,670,000 €	

Table 4.12 Transportation and disposal costs for Scenario 3

WWTP	Distance Between WWTP-Drying Plant	Annual transportation cost with 40 % maintenance cost	Disposal Plant where Sludge is Delivered to	Annual Drying Cost	Final Disposal	Distance between Drying-Final Disposal (Km)	Annual transportation cost with 40 % maintenance cost	Disposal Cost
HURMA	75.5	257,582 ₺	Hurma Thermal Drying and Cogeneration Plant Baturalp Solar Drying Plant	For the Part Delivered to Baturalp Solar Drying 5,840,000 ₺	AS Cement Plant	68,3	131,073 ₺	3.832.000 ₺
LARA	91.8	538,299 ₺	Baturalp Solar Drying Plant	11,169,000 ₺	Use on Soil	1	2,218 ₺	-
ELMALI	59.8	24,440 ₺						
KORKUTELİ	13.8	7,808 ₺						
BELDIBI	70.2	149,688 ₺	Kumluca Solar Drying Plant	It belongs to ASAT. therefore disposal cost is not determined.	Use on Soil	64	109,174 ₺	-
KEMER	56	59,704 ₺						
ÇAMYUVA	50	53,308 ₺						
TEKIROVA	44.6	15,850 ₺						
KUMLUCA	-	0						
KAŞ	93.2	30,165 ₺						
KALKAN	110	26,384 ₺						
FİNİKE								
DEMRE	40.5	9,597 ₺						
BOĞAZKENT	43.1	11,488 ₺	Mer-su Solar-Thermal Drying and Incineration Plant	-	For the part delivered to AS Cement Plant	123	157,364 ₺	2.737.500 ₺
SERİK 1	39.6	126,659 ₺						
SERİK 2								
ÇOLAKLI	25	13,327 ₺						
KUMKÖY	24.9	13,274 ₺						
TITREYENGÖL	29.9	10,626 ₺						
MANAVGAT	30.8	131,350 ₺						
İNCEKUM (AVSALLAR)	59	62,903 ₺						
TÜRKLER	68.2	72,711 ₺						
OKURCALAR	50	53,308 ₺			-	-	-	40.277.750 ₺
KONAKLI	76.2	162,481 ₺						
ALANYA	82.6	352,256 ₺						
OBA/TOSMUR/ CIKCILLI	91.2	194,466 ₺						
MAHMUTLAR	97.1	103,523 ₺						
GAZİPAŞA	131	46,510 ₺						
AKSEKİ	102	9,531 ₺						
İBRADI	37.8	1,141 ₺						
GÜNDOĞMUŞ	95.7	6,099 ₺						
	TOTAL	2,549,717 ₺		17,009,000 ₺			399,829 ₺	46,847,250 ₺

The required investment costs and treatment sludge transport/disposal costs within the scope of developed scenarios are summarized in Table 4.13; the ratio of treatment sludges to be disposed of and the possible treatment method is also given in the table on a scenario basis. As it can be seen in Table 4.13, the highest investment cost is calculated in Scenario-1. In this scenario, drying and incineration plants with high investment costs will be established or the capacities of existing plants will be increased. Although the initial investment cost is high, the thermal value of the sludge will be used and the energy obtained from the sludge is high. In addition, in this scenario where regional solutions are proposed, since the short-distance transportation and on-site disposal options are considered, the advantage of the scenario is that the total annual transport/disposal costs are the lowest among the 3 scenarios. Considering that 7.3% of the total treatment sludge is used in agriculture, this ratio in Scenario-1 is quite low when compared with other scenarios. The use of treatment sludge in agriculture is risky due to the presence of heavy metal, organic compound content, and pathogen, and it is not possible to predict how it will affect the soil in the long term.

Table 4.13 Investment and transport/ disposal costs according to the scenarios developed

	Investment Cost (€)	Transportation/ Disposal Cost (€/year)
Scenario– 1 Drying + Supplementary Fuel (35 %) Drying + Use in Agriculture (7.3 %) Drying + Incineration (57.7 %)	25,160,000 €	9,321,670 €
Scenario – 2 Drying + Supplementary Fuel (44.3 %) Drying+ Use in Agriculture (22.7 %) Drying + Incineration(33 %)	14,805,000 €	11,283,358 €
Scenario – 3 Drying + Supplementary Fuel (25.1 %) Drying + Use in Agriculture (41.8 %) Drying + Incineration(33.1 %)	14,670,000 €	10,933,841 €

As it can be seen on the table, Scenario-3 is the option with the lowest initial investment cost. Because in this scenario, the capacities of the existing plants except for Mer-su Solar-Thermal Drying and Incineration Plant are preserved. In Mer-su Solar-Thermal Drying and Incineration Plant, the capacity of thermal drying units was increased. In addition, solar drying was preferred due to the low investment cost for the drying plant planned to be built in Kumluca. In this scenario, the annual transport/disposal costs are also lower when compared with Scenario-2. When evaluated in terms of costs, it is considered as a very reasonable and advantageous option. However, in this scenario, the agricultural usage rate of sludge is quite high. Considering the aforementioned reasons, Scenario-3 was not considered a viable solution although it is the most appropriate option in terms of costs due to the high rate.

In Scenario 2, the planning of capacity increases only in existing thermal drying plants has kept the investment costs at a very reasonable level. However, as can be seen on the table, 44.3% of the total sludge is delivered to the final disposal as additional fuel after drying. The use of 22.7% of total sludge in agriculture after current solar drying is optimal. Considering the aforementioned assessments, Scenario-2, where both investment cost and application rate in agriculture are relatively low and the use of sludge for beneficial purposes is high is considered as a more feasible option.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The amount of sludge increases day by day, and to establish an appropriate sludge management system is a very significant issue in wastewater treatment plants. It is especially important for the touristic region, such as Antalya, for both environmental and economic points of view. In the scope of this thesis, it was aimed to generate applicable sludge management alternatives for Antalya, where sludge management is a problem in the existing situation. For this purpose, three alternative scenarios were developed considering both investment and operating costs. In accordance with this study, the following conclusions were obtained:

- In the stage of scenario generating, primarily the locations of existing sludge disposal facilities, and capacities are taken into consideration. During the planning phase of, the capacity increase of the existing facilities and the location of the new facilities; a regional scale was taken as a basis. In any case, an investment cost of between 15 and 25 million Euros is needed to manage the sludge formed in Antalya properly.Transportation/disposal cost of the sludge is around 60–70 million ₺/year.

- In Scenario-1, the initial investment cost is determined as 25,160,000 €. The annual disposal and transportation costs are calculated as 9,321,670 €/year. This amount is the least of the three scenarios. In Scenario-1, 57.7%, 35% and 7.3% of total produced sludge will be disposed of in incineration plants, in cement factories as a supplementary fuel, and in soil, respectively. The advantage of this scenario is the high rate of treatment sludge disposal in order to get energy; disposed of in soil rate is the lowest among the three scenarios. The other advantage of this scenario is the annual disposal and transportation costs have the lowest value among the three scenarios. The high initial investment cost is the disadvantage of this scenario and the reason why it is the least feasible option among the three scenarios.

- In Scenario-2, the initial investment cost is 14,805,000 €and the cost of disposal and transportation is calculated as 11,283,358 €/year. In this scenario, 33.0%, 44.3% and 22.7% of total produced sludge will be disposed of in incineration plants, in cement factories as a supplementary fuel, and in soil, respectively.The disadvantage of this scenario is that annual disposal and transportation costs have the highest value among the three scenarios. With low initial investment cost, disposal of sludge to obtain energy and disposed of in soil proportional distribution of percentages is the advantage of the scenario.

- In Scenario-3, the initial investment cost was 14,670,000€ and the disposal and transport cost was calculated as 10,933,841 €/year. The total sludge produced; 33.1% will be incinerated, 25.1% as disposed of as supplementary fuel, 41.8% will be disposed of using soil. The advantage is that it has the lowest initial investment cost among the three scenarios and the relatively low annual transport and disposal costs. The disadvantage of the scenario is the highest percentage of agricultural use, which is the reason why the applicability of the scenario is low.

- As a result, when we evaluate in terms of cost and benefit; of these three scenarios, Scenario-2 is considered to be the most feasible option.

5.2 Recommendations

Sewage sludge management is an indispensable process in the operation of wastewater treatment plants. The basis of today's problem is that has been ignored during the planning phase of wastewater treatment plants. Improvements should be made to the sludge dewatering units of existing wastewater treatment plants to solve problems. During the planning stage of new facilities, attention should be paid to the units for sludge disposal.

In order to facilitate sludge disposal, wastewater treatment plants and integrated sludge disposal facilities should be constructed by planning at a regional scale. In this way, initial investment and operating costs are expected to decrease. In addition, it is important to build facilities to reduce operating costs, amortize the initial investment cost in a short period of time, and to generate energy for environmental health. For this purpose, the number of facilities such as biogas, gasification, pyrolysis, and incineration should be increased.

In addition, soil analysis and applicability of sludge to the soil should be investigated in large-scale researches in Antalya regarding the use of stabilized sewage sludge in soil, which is a cheaper option. Pilot studies should be initiated immediately in an appropriate zone.

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