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Research Article

# Decision making in Sewage sludge dewatering equipment selection: AHP approach

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**Abstract**

The sewage sludge which happened during the treatment of wastewater must be dewatered before they are disposed of. Sludge with reduced water content can be easily processed and significantly reduces disposal costs. For this reason, when determining the sludge dewatering process in a wastewater treatment plant, it is necessary to choose low-cost methods that are suitable for the plant and provide high solids content. Equipment selection is an important issue. Inappropriate equipment selections negatively affect plant efficiency, production, precision, and especially the cost of sludge dewatering. On the other hand, it can be done easily with multi-criteria decision-making methods to choose the best equipment among many alternatives. In this study, sludge dewatering equipment, which is frequently used in Turkey, was evaluated using the analytical hierarchy process (AHP), one of the well-known multiple decision-making methods, by taking expert opinions. The criteria were created for the selection of sludge dewatering equipment, these criteria were compared and analyzed in the SuperDecision software and the best sludge dewatering equipment was determined.

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## ARITMA ÇAMURLARI SUSUZLAŞTIRMA EKİPMAN SEÇİMİ İÇİN ÇOK KRİTERLİ KARAR VERME: AHP YAKLAŞIMI

**Özet**

Atıksuyun arıtılması sırasında oluşan arıtma çamurları, bertaraf edilmeden önce susuzlaştırılmalıdır. Azaltılmış su içeriğine sahip çamur kolayca işlenebilir ve bertaraf maliyetlerini önemli ölçüde azaltır. Bu nedenle bir atıksu arıtma tesisinde çamur susuzlaştırma prosesi belirlenirken tesise uygun ve yüksek katı içeriği sağlayan düşük maliyetli yöntemlerin seçilmesi gerekmektedir. Ekipman seçimi önemli bir konudur. Uygun olmayan ekipman seçimleri tesis verimliliğini, üretimini, hassasiyetini ve özellikle çamur susuzlaştırma maliyetini olumsuz etkiler. Öte yandan, birçok alternatif arasından en iyi ekipmanı seçmek çok kriterli karar verme yöntemleri ile kolaylıkla yapılabilmektedir. Bu çalışmada, Türkiye'de sıklıkla kullanılan çamur susuzlaştırma ekipmanları, çok iyi bilinen çoklu karar verme yöntemlerinden biri olan analitik hiyerarşi süreci (AHP) kullanılarak uzman görüşleri alınarak değerlendirilmiştir. Çamur susuzlaştırma ekipmanı seçimi için kriterler oluşturulmuş, bu kriterler SuperDecision yazılımında karşılaştırılarak analiz edilmiş ve en iyi çamur susuzlaştırma ekipmanı belirlenmiştir

**Anahtar Kelimeler**
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**INTRODUCTION**

Sewage sludge is a residue produced in wastewater treatment plants (WWTPs) [1]. The treatment of sludge is one of the most controversial subjects in modern WWTPs. Advanced wastewater treatment technologies have resulted in higher quality wastewater, but some have also increased the amount of sludge produced in the process. To dispose of the sewage sludge, it must first be dewatered.

Sludge dewatering is a basic process used to reduce the water content of the sludge. It is necessary to dewater the sludge before sludge drying, agriculture use, incineration, composting, and storage processes [2]. As the volume of sludge is reduced by dewatering, the cost of transporting the sludge to the final disposal site is significantly reduced. The dehydrated sludge is easier to process than dense or slurry. In some cases, it is necessary to dewater the sludge in order to prevent the odor of the sludge.

There are many methods used for sludge dewatering in WWTPs [3]. These methods can be grouped into two: natural dewatering and mechanical dewatering. Large land is needed for natural dewatering. Since it is not a problem to find large lands in small-capacity facilities, natural dewatering can be applied. However, the dewatering process of land is a problem in large-capacity plants and plants located in densely populated cities. In short, mechanical dewatering is preferred in regions with limited space. Mechanical dewatering is carried out using different dewatering equipment. The SD equipment is evaluated by the facility managers according to some criteria and the appropriate dewatering equipment is selected for the facility.

The selection of multi-purpose equipment is a crucial activity in effective plant operation. Selection of the most suitable equipment is important because the selection of inappropriate equipment will negatively affect the efficiency, operation, and cost of a facility [4]. Appropriate equipment selection can increase system efficiency and ensure effective use of the workforce. On the other hand, insufficient equipment selection may reduce the efficiency of the process. Selecting more qualified equipment than necessary may lead to excessive operating costs. Thus, it is a difficult task to carry out for engineers and managers, and even for equipment manufacturers and vendors [5]. The equipment selection should be done carefully. There are studies in the literature that deal with the equipment selection problem using different methods. Several methods exist for multi-criteria decision-making (MCDM) in equipment selection [5]. There are no better or worse techniques, but some techniques better suit to particular decision problems than others do [6]. Among these methods, the most popular ones are scoring models (Nelson 1986), analytic hierarchy process (AHP), analytic network process (ANP), TOPSIS, and PROMETHEE [6], [7]. Researchers showed in their study that optimum decisions can be made by using the AHP method in environments where there are too many criteria for equipment selection and multiple solution alternatives [8], [9].

This paper, this study aims to evaluate and decide on the most suitable sewage dewatering equipment. In the study, it was tried to decide on the most suitable of four different mechanical sewage dewatering alternatives that can be used in WWTPs in Turkey with the AHP method, which is one of the multi-criteria decision-making methods.

## SLUDGE DEWATERING PROCESSES

Sludge represents only 1% or 2% of treated wastewater but contains 50% to 80% of pollution. The operating cost for sludge treatment can be around 50% of the total operating cost of the WWTP [10]. Therefore, it is appropriate to optimize sludge management so that the sludge (waste) treatment cost is as low as possible [11].

SS produced at various stages of wastewater treatment may contain only 0.25% dry solids (DS) [12]. It must be thickened further to reduce the amount of water, resulting in lower economic demands [13].

SS can be carried out efficiently with mechanical equipment. Experts working on the design and operation of Turkish treatment plants stated that four different types of equipment are frequently used. These equipment are filter press (SD-1), belt press (SD-2), decanter (SD-3) and screw press (SD-4). However, each has a different dewatering performance and different technical characteristics. According to expert opinions, these equipment are explained as follows.

According to experts, the efficiency of SD depends on whether the plant is working well or not. If the WWTP is not operated well, the efficiency to be obtained from the sludge equipment may decrease. In other words, with the efficient operation of sewage dewatering, it can be said whether the treatment plant is working well or not.

**SD-1:** Plate and frame filter presses, recessed plate presses, and membrane plate presses are all used to dewater sludges [14]. It is a classical system that has been used for a long time. In practice, it is stated that sludge can be discharged with this equipment at most. SD-1 provides a good solids content of 30-50% [14]. DS compared to other equipment. However, manpower is required for its cleaning. The applicability of the SD-1 decreases after a certain flow rate. Because a lot of labor is needed. SD-1 needs to be emptied its sludge max. 2 or 3 times. Because the SD-1 has drying times. Therefore, the manpower increase. But, it is seen that SD-1 has started to prefer in applications.

**Figure 1**. Filter press

**SD-2**: Belt filters are characterized by two continuous, tensioned filter cloths. It is not a frequently used equipment and is just preferred. It can be achieved 30-35% DS [15]. It has a working principle similar to the SD-1, but it is equipment produced to require less manpower compared to the SD-1. Unlike the SD-1, the machine throws the sludge and water itself. The sludge feeding time is shorter compared to the SD-1 and therefore the DS% is between 20-30%, lower than the SD-1.

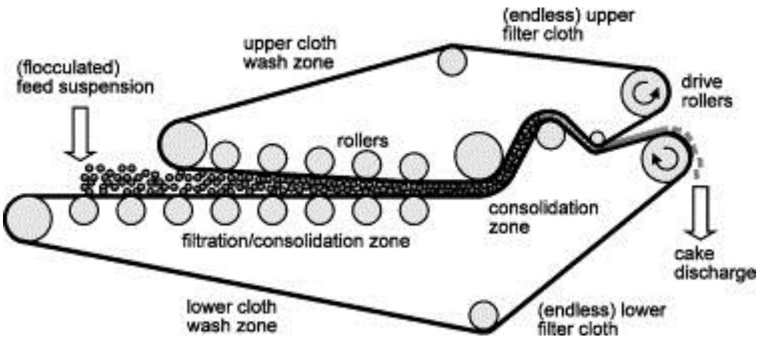


**Figure 2.** A typical belt press filter.

**SD-3**: High solids decanters are used to mechanically dewater environmental and biosolids sludge and are often a preferred choice of equipment. They are equipment that was designed as an alternative to all other equipment. They separate water and sludge from each other by using centrifugal force. Compared to all other equipment, the manpower is less. By adjusting its system, it is ensured that SD is performed by the machine. However, the DM varies between 20-30% [15].

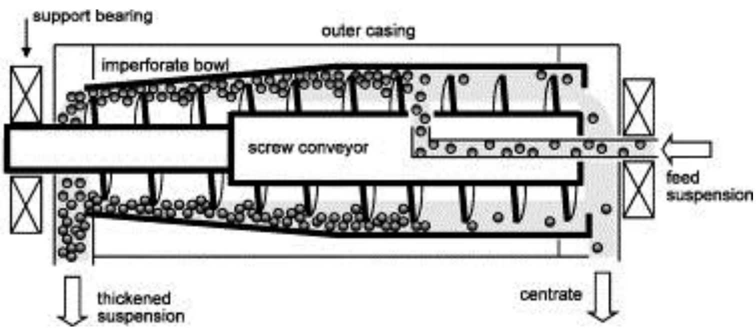


**Figure 3**. A decanter centrifuge.

**SD-4:** It is equipment equal to the SD-2 in terms of working principle. It does all the work that the SD-3 does. It can dewater the same amount of sludge by consuming less energy than the SD-3. However, the equipment of the SD-4 wears away. This situation creates a disadvantage for this equipment.

Additionally, it has been stated that the working time of the SD-1 is longer than other equipment. The SD-3 are processes that can dewater sludge in the shortest time, but require excessive energy. For example, while the energy requirement is zero in the SD-1, it goes up to 5-6 kW in the SD-4 and SD-2, and up to 40-45 kW in the SD-3. When compared in terms of the land requirement for equipment of the same capacities, the SD-3 and SD-4 require less land compared to the Sd-1 and SD-2.

## AHP PRINCIPLES

Analytical Hierarchy Process (AHP) is one of the multi-criteria decision-making techniques developed by Thomas L. Saaty in 1977 [16]. AHP is a mathematical method that takes into account the priorities of the group or individual and evaluates qualitative and quantitative variables together in decision-making. The use of people statements in decision-making problems has increased remarkably recently. With AHP, it is tried to provide the opportunity to recognize their decision-making mechanisms by taking into account the observations of decision-makers in different psychological and sociological situations. With this method, it is aimed that decision-makers make more effective decisions. The method has received a great deal of attention and has been used in solving many decision-making problems in real life. In AHP, the first step is to determine the factors and the sub-factors belonging to the factors in line with the purpose of the decision-maker. In AHP, first, the purpose is determined and the factors affecting the purpose are tried to be determined in line with this purpose, at this stage, a survey study or the opinions of experts on this subject can be consulted to determine all the factors affecting the decision process. After the purpose, factor and sub-factors are determined, pairwise comparison decision matrices are created to determine the importance of factors and sub-factors among themselves. The importance scale of 1-9 proposed by Saaty is used in the creation of these matrices. The importance scale of 1-9 suggested by Saaty provides the best results [16].

In Table 1, the importance scale values and their meanings are explained. Values such as 2, 4, 6, 8, which are not in the degree of importance, are intermediate values. For example, if the decision-maker is undecided between 1 and 3, he can use the value 2. Pairwise comparisons are the most important stage of AHP. Relative or absolute measurements are used to obtain pairwise comparisons. According to the information obtained from these, judgments are converted into a matrix in AHP. aij, i. with feature j. If the feature is displayed as a binary comparison value, it is obtained from the equation aji=1/aij. This property is called the reciprocity property. The second step of AHP is the generation of normalized matrices. The normalized matrix is obtained by dividing each column value separately by the corresponding column sum. Starting from the normalized matrix; The average of each rank value is taken. These obtained values are the percent importance weights for each criterion. The Consistency Ratio should be calculated in order to measure whether the decision-maker behaves consistently when making comparisons between criteria. In this calculation, random index numbers are used depending on the number of n criteria. If the value found as a result of the calculations is below 0.10, it is concluded that the comparison matrix created is consistent. Otherwise, the decision matrix should be rearranged. The last step of the AHP is to multiply the importance weights of the criteria with the importance weights of the alternatives and to find the priority value of each alternative. The sum of these values is equal to 1. The alternative with the highest value is the best alternative for the decision problem [16].

**Table 1.** The importance scale and its description

| Definition | İntensity of importance |
|---|---|
| Equall important | 1 |
| Moderately more important | 3 |
| Strongly more important | 5 |
| Very strongly more important | 7 |

| | |
|---|---|
| Extremely more important | 9 |
| İntermediate values | 2, 4, 6, 8 |

## APPLICATION

The research is the evaluation of four different mechanical SD equipment, which are frequently used in Turkey, by applying AHP,

Firstly, it was established the Hierarchical Structure: At this stage, with the help of decision-making experts/experts, the alternatives to be evaluated regarding the equipment selection and the criteria (n) to be used in the selection of the alternatives, and the definition of the problem were made. One of the most important properties of this method, "evaluation of the criteria independently", is important in determining the main criteria group that is most suitable for the purpose and which can be analyzed and, if necessary, the sub-criteria groups connected to this main criteria group. Within the scope of the study, the five different criteria were defined for the four dewatering equipment used. The hierarchy for the most suitable equipment selection, which constitutes the first step of the study, is given in Figure 4.

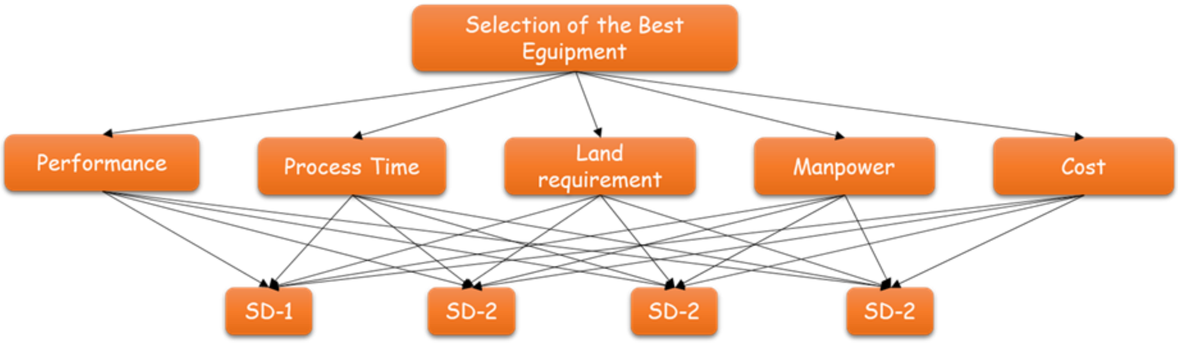


**Figure 4.** Then decision hierarchy of equipment selection

Secondly, four alternative mechanical dewatering equipment determined in the hierarchy were compared for the main criterions, and each criterion according to the importance scale suggested by Saaty.

**Table 2.** Pairwise comparison matrix by main criterions

| Criteria | Performance | Process Time | Land | Manpower | Cost |
|---|---|---|---|---|---|
| Performance | 1 | 5 | 5 | 5 | 1 |
| Process Time | 1/5 | 1 | 2 | 1/2 | 1/5 |
| Land | 1/5 | 1/2 | 1 | 1/2 | 5 |
| Manpower | 1/5 | 2 | 2 | 1 | 1/5 |
| Cost | 1 | 5 | 5 | 5 | 1 |

In the comparison according to the performance criteria, a pairwise comparison was made by considering the DS percentages of the sludge dewatering equipment. A sample pairwise comparison matrix created accordingly is given in Table 3.

**Table 3.** Pairwise comparison matrix by performance criterion

| Performance | SD-1 | SD-2 | SD-3 | SD-4 |
|---|---|---|---|---|
| SD-1 | 1 | 7 | 7 | 7 |
| SD-2 | 1/7 | 1 | 1/2 | 1/2 |
| SD-3 | 1/7 | 2 | 1 | 1 |
| SD-4 | 1/7 | 2 | 1 | 1 |

The sludge dewatering time or the working time can be taken into account in the comparison in the treatment time criterion. An example pairwise comparison matrix created according to these is given in Table 4.

**Table 4.** Pairwise comparison matrix by process time criterion

| Process Time | SD-1 | SD-2 | SD-3 | SD-4 |
|---|---|---|---|---|
| SD-1 | 1 | 1/4 | 1/5 | 1/5 |
| SD-2 | 4 | 1 | 1/2 | 2 |
| SD-3 | 5 | 2 | 1 | 2 |
| SD-4 | 5 | 1/2 | 1/2 | 1 |

In the land requirement criterion, matrices were created by comparing the area requirements for mechanical dewatering equipment. In comparison, equipment with less need for rated space was seen as superior and rated with a higher score (Table 5).

**Table 5.** Pairwise comparison matrix by land requirement criterion

| Land | SD-1 | SD-2 | SD-3 | SD-4 |
|---|---|---|---|---|
| SD-1 | 1 | 1/2 | 1/2 | 1/3 |
| SD-2 | 2 | 1 | 1/2 | 1/2 |
| SD-3 | 2 | 2 | 1 | 1 |
| SD-4 | 3 | 2 | 1 | 1 |

In the manpower criterion, the employee requirement for the equipment used can be taken into account. The equipment that does not require manpower is considered superior and rated as such. In this way, a pairwise comparison can be made (Table 6).

**Table 6.** Pairwise comparison matrix by manpower criterion

| Manpower | SD-1 | SD-2 | SD-3 | SD-4 |
|---|---|---|---|---|
| SD-1 | 1 | 1/5 | 1/7 | 1/7 |
| SD-2 | 5 | 1 | 1/3 | 1/3 |
| SD-3 | 7 | 3 | 1 | 3 |
| SD-4 | 7 | 3 | 1/3 | 1 |

In the selection of sludge dewatering equipment, the energy requirement, operation, investment and maintenance costs of the equipment can be taken into account while making pairwise comparisons according to the cost criteria. For this work, equipment with low energy and other costs for sludge dewatering was evaluated as superior. An example pairwise comparison matrix created according to these is given in Table 7.

**Table 7.** Pairwise comparison matrix by cost criterion

| Cost | SD-1 | SD-2 | SD-3 | SD-4 |
|---|---|---|---|---|
| SD-1 | 1 | 3 | 4 | 3 |
| SD-2 | 1/3 | 1 | 5 | 1 |
| SD-3 | 1/4 | 1/5 | 1 | 1/5 |
| SD-4 | 1/3 | 1 | 5 | 1 |

In the AHP application, the generated pairwise comparison matrices were entered into the Super Decision program and evaluated. As a result of this evaluation, equipment priorities and consistency ratios of the created pairwise comparison matrices were obtained based on each criterion. The obtained values showed in Figure 5.

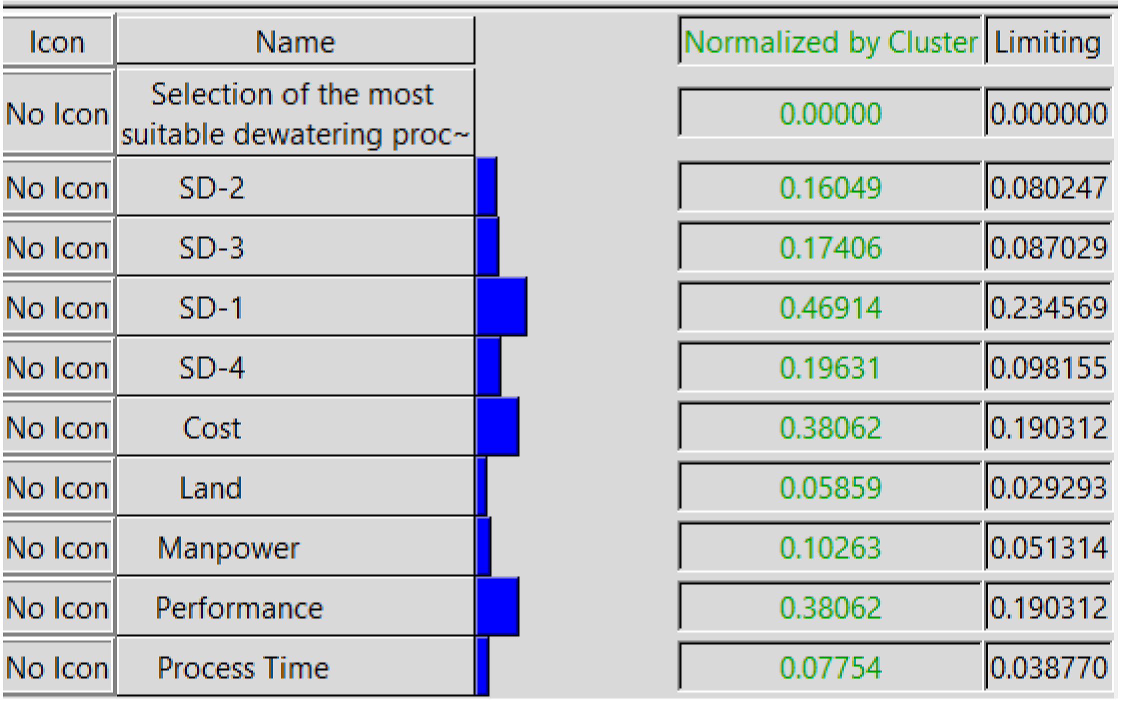


**Figure 5**. Priorities and consistency ratios based on criteria

The upper limit for the consistency ratio (CR) obtained for each pairwise comparison matrix is required to be 0.10. A ratio above 0.10 indicates an inconsistency in the judgments of the decision-maker. In this case, judgments need to be improved. In this study, consistency rates were obtained with 0.03<0.1 and below 10%. With AHP, equipment performance and cost were determined as the most important criteria in the equipment selection process.

The most suitable filtration equipment designs for sludge dewatering have been developed to meet the unique characteristics of sludges, the most important of which is their compressibility and fine particle sizes, resulting in cakes with exceptionally high solids content close to the filter media. Sludge dewatering equipments such as filter press, belt press, and decanter centrifuge have become the most widely accepted machines. To ensure the same sludge feed characteristics, highest dewatering rates and best permeate clarity, the correct selection of dewatering equipment is essential.

As a result of this study, SD-1 was the best equipment in terms of performance and cost. In order of preference, it was SD-1>SD-4>SD-3>SD-2. It is known both in practice and literature studies that SD-1 tends to give drier solids. while SD-4 has emerged as the 2nd preferred equipment since it provides less dry matter content than SD-1. Compared to Sd2- and Sd-3, less energy cost made SD-4 stand out. According to this study, SD-4 can be preferred instead of SD-1 for facilities that require less manpower.

## CONCLUSION

In this study, a decision approach is presented for the selection of sludge dewatering equipment with the Analytic Hierarchy Process (AHP) method, which is one of the Multi-Criteria Decision Making (MCDM) methods. It is shown how AHP can be applied to the dewatering equipment selection problem and how multiple criteria can be included in the selection problem in practice. First, suitable criteria for the equipment selection problem were determined by the experts in the mechanical dewatering equipment used in Turkey. Determining criteria are performance, process time, space requirement, manpower requirement, and cost. For this study, the equipment with the best dewatering performance was determined as SD-1, that is, filter press. The most important factors to be considered in practice are the determination of the target and criteria by experts and the creation of consistent pairwise comparison matrices. By adding additional criteria to the criteria given in this study, the best equipment for the facility can be selected by evaluating with AHP.

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