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Sustainable Design of Stormwater Runoff Treatment Systems for Small Airports

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Abstract: Airports designated with special status; where, rather than passenger and cargo transportation; pilot, parachute, model plane and glider trainings are conducted mostly, have important functions in Turkey. They are much smaller than other commercial airports in terms of the space they occupy and the aircrafts that use the same. Nevertheless, wastewater is produced due to runways and other impervious surfaces, though much less than large airports. Therefore, in terms of waste management, it is important to eliminate wastewater that originates from these areas and to include them in waste management plans besides other pollutants. This is even more important especially in small airports that are located on drinking water basins. In this study, exemplary effective and low cost treatment systems, which are easy to construct and manage and intended to treat pollutants which may be carried by stormwater runoff from asphalt and other impervious surfaces of small airports are discussed. According to a research conducted under meteorological conditions of Istanbul, BOD5 and heavy metal removals are taken as basis in these exemplary treatment systems. It has been calculated and recorded that required constructed wetland system area is 397m^2 based on the estimated removal efficiency of 95% and the lowest average water temperature for Istanbul. On the other hand, preliminary treatment system that consists of filtration and settling pond has a volume of 20 m^3 and has the capacity to discharge into a further treatment system following the preliminary treatment depending on the conditions.

Key words: Airport stormwater runoff, low cost treatment, constructed wetlands, settling ponds, runoff treatment

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Özet: Yolcu ve kargo taşımacılığı dışında daha çok pilot, paraşüt, model uçak, planör eğitimlerinin yapıldığı özel statülü havalimanları Türkiye'de önemli görevler üstlenmektedir. Bunlara kapladığı alanlar ve kullanılan hava araçları açısından bakıldığında diğer ticari havalimanlarından çok daha küçüktür. Bununla birlikte büyük havalimanlarından çok daha az miktarlarda olsa da pist ve diğer geçirimsiz alanlardan atıksu oluşumu söz konusudur. Bu sebeple atık yönetimi açısından bu alanlardan kaynaklanan atıksuların bertaraf edilmesi önemlidir ve diğer kirleticilerle birlikte atık yönetimi planlarında yer alması gerekmektedir. Özellikle içme suyu havzalarında bulunan küçük havalimanlarında konu daha önem kazanmaktadır. Bu çalışmada küçük havalimanlarının asfalt veya diğer geçirimsiz alanlarından yüzey akışla gelebilecek kirleticilerin belli bir oranda gideriminin sağlanması amacıyla inşa ve işletimi kolay, etkili ve aynı zamanda inşa masrafları da düşük olan örnek arıtma sistemleri ele alınmıştır. İstanbul meteorolojik şartlarına göre yapılan araştırmaya göre bu örnek arıtma sistemlerinde BOD_5 ve ağır metal giderimleri esas alınmıştır. Yapılan hesaplamalara göre İstanbul için en düşük ortalama su sıcaklığında ve öngörülen %95 giderim verimine göre gerekli yapay sulakalan sistem alanı 397m^2 olarak kaydedilmiştir. Bununla birlikte filtrasyon ve çöktürme havuzundan oluşan diğer ön arıtma sistemi ise 20 m^3'lük bir hacme sahip olup ön arıtım sonrası bulunduğu koşullara göre daha ileri arıtım sistemine deşarj edilebilme özelliğindedir.

Anahtar kelimeler: Havaalanı yüzey akış suları, düşük masraflı arıtma, yapay sulakalanlar, çöktürme havuzları, yüzey akış suları arıtımı

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1. Introduction

Airport stormwater runoff may contain harmful chemicals that can pollute surface and ground water (Baxter et al. 2019). While they may originate from miscellaneous chemical de-

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icing/anti-icing preparations used for aircrafts, they may also come from maintenance and repair of airport and mineral oil spills from shuttles, herbicides and similar wastes. Besides that, emissions that arise from fuels of aircrafts can release pollutants onto runways especially during take-off. Airport pollutants are generally combustion gasses (CO_2, NO_x, sulfate ions and particulate matters), hydrocarbons, PAHs, detergents, several toxic metals, specific organic chemicals, cyanides, pesticides and several alkali and acidic chemicals (Sulej et al., 2011). The most significant de-icing/anti-icing chemicals used for aircrafts are propylene glycol- or ethylene glycol-based chemical agents. According to studies, Biological Oxygen Demand (BOD_5) values of such chemical agents in airport stormwater runoff can be as high as 245,000mg/l (Switzenbaum et al., 2001). BOD_5 values of several chemical de-icing/anti-icing chemical agents in pure form can range from 270.000 to 590.000 mg/l while their Chemical Oxygen Demand (COD) can range from 330.000 to 1.390.000 mg/l (Freeman et al., 2015). According to USEPA (1995), de-icing/anti-icing chemical agents can be applied around 2-4m^3/plane/flight in large commercial aircrafts (USEPA, 1995). In a study conducted on potassium acetate and sodium formate which are two of the de-icing/anti-icing chemical agents used in the United States of America, it was reported that acute toxicity of these compounds on different organisms in the aquatic environment ranges between 298 and 6560 mg/l for potassium acetate (as acetate) and between 1780 and 4130 mg/l for sodium formate (Corsi et al., 2009). Airport stormwater runoff does not only contain de-icing/anti-icing chemical agents they also contain many parameters included on the list of primary pollutants. These may be chrome (as chromate), cadmium, platinum, copper, nickel, lead, zinc as heavy metals; Benzopyrene, Naphthalene and Pyrene as PAH; Phenmedipham, Pendimethalin, Terbuthylazine and Glyphosate as Herbicide (Malaviya and Singh, 2012).

Nonetheless, many different treatment technologies are available to treat wastewater that originates from airports. In a study conducted in USA, analysis of wastewater treatment systems used in 107 airports all around the world revealed that there are several treatment systems which are highly different from one another such as anaerobic fluidized bed reactor, activated sludge, mechanical vapor recompression, algal treatment, aerated lagoons, reverse osmosis, constructed subsurface flow wetlands, non-aerated lagoons, industrial recycling, in situ soil/irrigation treatment, aerated gravel beds, reciprocating gravel beds, moving bed biofilm reactors (ACRP,2013). While COD removal efficiency in wetland systems is 10 to 80% in studies conducted for treatment of airport stormwater runoff in America, it can be as high as 100% in case of anaerobic treatment (Freeman et al., 2015). It has been revealed that BOD_5 removal efficiency is approximately 76% in horizontal subsurface flow constructed wetland systems through which stormwater runoff is treated in Heathrow Airport, the largest airport in England (Adeola et al., 2009). This treatment system is a good example of the fact that de-icing/anti-icing chemical agents which are used intensively can be treated. Moreover, it is indicated that TOC removal efficiency in airport stormwater runoff is kept within the range of 76-98% by use of a passive filtration system that includes zeolite and perlite (Pressl et al., 2019).

Low Impact Development (LID), which is a part of Green Infrastructure, has been increasingly implemented on different parts of the world, primarily in USA and Canada, both in urban areas and areas that consists of large amount of impervious surface such as airports. Manuals are available for different locations as to LID practices which have become increasingly popular especially for the last 10 years (LID, 2010a; LID, 2010b; LID, 2014). Seattle-Tacoma International Airport, Beijing Daxing International Airport and Tianjin Airport can be given as an example within the scope of works carried out for design and guide prepared for implementation of such sustainable concepts in airports (LID, 2018; Li et al., 2020; Peng et al., 2021). LID applications embody sustainable reduction dynamics for not only de-icing/anti-icing pollutants but also many other pollutant parameters.

The airports that are designated with special status in Turkey are Istanbul Hezarfen Airport, Aydın Çıldır Airport, Eskişehir Hasan Polatkan Airport and İzmir Selçuk-Efes Airport and important activities such as pilot, parachute, model plane and glider trainings are carried out in these fields (URL, 2021)

This study aims to retain, remove and manage significantly various pollutants which originate from above-mentioned small airports and can be possibly carried to receiving medium through stormwater runoff. Istanbul has been chosen specifically because it is easier to obtain meteorological data. However, the purpose is to use it as a reference point for other small airports as well. Nevertheless, it is also possible to use similar treatment systems for other large airports with enough space (as in the case of Heathrow/London airport).

2. Methodology

In this study, primarily meteorological data is addressed because amount of rainfall that may generate stormwater runoff must be calculated based on the meteorological data in the places where these airports are located so that polluted water which may be carried through stormwater runoff from the asphalt zones of small airports, that are run for training and similar purposes, to receiving mediums can be calculated. The study also covers design approaches which demonstrate how airport stormwater runoff in Istanbul and consequently, in other cities of Turkey, can be treated. The purpose of the study is to ensure treatment and retention of pollutants to a certain amount, which may originate only from runways and other impervious surfaces of airports. There is no data available as to whether de-icing/anti-acing chemical agents are used or to what extent they are used in Turkey's small airports. If such chemical agents are used, the site of application must be prepared appropriately and spilled chemicals must be collected so that they can be reused or treated/disposed properly. However; it is known that although required treatment processes are implemented in the site of application when de-icing/anti-acing chemical agents are used, such chemicals that are left on the plane generate pollution load on impervious surfaces besides other chemicals when planes taxi. Therefore, the treatment system design calculations focus mostly on treating pollution generated by chemicals spilled on runways. Runway length is taken as 1000 m and width as 25 m to make sure that it can set an example for all of the small-scale airports in Turkey in terms of design approach.

3. Result and discussion

According to data from General Directorate of Meteorology (MGM), average amount of annual rainfall was 677.2 mm in Istanbul between 1929 and 2019 (MGM, 2021). The rainiest seasons in Istanbul are winter, fall, spring and summer respectively. While average rainfall was 76.3 mm for December, January and February; average rainfall for September, October and November was 68.3 mm (MGM,2021). However, during some periods, rainfall occurs longer and more than the expected. For example, the highest rainfall recorded by Florya observation station that is in the closest proximity to Büyükçekmece Lake Basin was 112.5 kg/m^2 and occurred on October 04, 1942. The highest amount of rainfall in overall Istanbul was measured on September 10, 1981 and it was 136.1 (MGM, 2021). In the calculations in this study, Florya meteorological observation station data was used because it is close to the airport with special status in Istanbul and 112 kg/m^2 was accepted. One of the critical parameters for design of the treatment systems that will be used in this study is rainfall intensity rather than the duration. The most important aspect that must be considered at this point is that in case of rain shower when the rainfall intensity is the highest, stormwater runoff generated by polluted water must be directed to the treatment system during the first 5-10 minutes after the onset of rainfall and to the receiving medium for the time remaining. Therefore, this study is based on such 10 minute duration. Other studies reveal that it is more effective to treat stormwater runoff during the period when it is first generated than other times. For example, treatment effectiveness factor for the first 10% of total stormwater runoff volume is 7 times higher than the stormwater runoff that is generated for the time remaining (Stenstrom and Kayhanian, 2005). It is indicated in another similar study that majority of pollutants carried come with the first 30% of the stormwater runoff (Li-qing et al., 2007). Therefore, pollution generated at the beginning of rainfall is worthy of attention. Bypassing stormwater runoff generated in other times of rainfall is another safe option in small airports with limited space. Otherwise, treatment systems with small capacity may become disabled due to heavy rain in areas with limited space. However; under normal rainfall conditions, it is possible to direct polluted water to a treatment system for 30-60 minutes after the onset of rainfall. Amount of wastewater produced from runway or impervious surfaces for a certain period of time, estimated runway size, size of the system through which wastewater is planned to be treated and other specifications are indicated on Table 1 in line with the highest amount of daily rainfall recorded to be on the safe side. It is a fact that de-icing/anti-icing chemical agents used in planes must be recovered to a great extent or, in other words, site of application for such chemical agents must be controlled against pollution; therefore it can be stated that the main source of chemical agents which may exist in runway areas is only the chemicals that are carried through rainfall from fuselage to the surface. In addition to that, runway areas are protected against icing by use of various chemicals. Therefore, it is worth to notice that they may also produce pollution. According to a four years study in a medium-sized airport in the United States, samples taken at various times from snow masses accumulated by airport snow-banks, onto which de-icing/anti-icing chemical agents were used, were analyzed and average glycol concentrations were found to be in the range of 65 and 5940 mg/l and it was reported that such concentrations correspond to 0.17 – 11.4 % of the glycol applied to planes (Corsi, et al., 2006). Wastewater input BOD_5 value given on Table 1 has been calculated taking 0.17% as the basis, which is the minimum estimated rate of propylene glycol- or ethylene glycol-based chemicals that can exist in runways. This value corresponds approximately to 400 mgO_2/l. Treatment system that has been sized in accordance with the values given on Table 1 is shown on Figure 1. The Reed, Crites & Middlebrooks (1995) equation is used in the design calculations in Table 1.

The general form of the Reed, Crites & Middlebrooks (1995) equation is given below (Eq. 1):

$$A_s = \frac{Q\,(\ln C_0 - \ln C_e)}{K_T\, d\, \eta} \qquad (1)$$

where:

A_s = Superficial area of the bed

Q = daily mean hydraulic load

C_0 = Inlet concentration

C_e = Outlet concentration

K_T = removal rate constant at T °C

d = average depth of the treatment bed

η= porosity (*dependent on media selected*)

Table 1. Design parameters of airport stormwater runoff that can be treated through wetland system

Design parameters of system	Calculated values	Units
Max. daily precipitation	112	kgm^{-2}
Max. daily flow (1000x25 m due to the size of the runway)	20	$m^3 10^{-1}$ *minutes*
Inlet organic load as BOD_5	400	mgO_2l^{-1}
Water minimum temperature (*assumed*)	10	*°C*
Water height in the bed (HF) (*assumed*)	0,70	*m*
Hydraulic gradient of the HF beds (S)	0,010	-
Slope of the beds (*assumed*)	1	*%*
Porosity of the filling media (η)	0,35	*Gravel diameters 8 mm*
Theoretical hydraulic conductivity (ks)	500	$m^3m^{-2}d^{-1}$
Removal (%) with water temp= 10° C as BOD_5	95	*%*
Total area	397	m^2
Geometry of each bed		
Width	28,5	*m*
Length	14	*m*
Inlet depth	0,55	*m*
Outlet depth	0,85	*m*

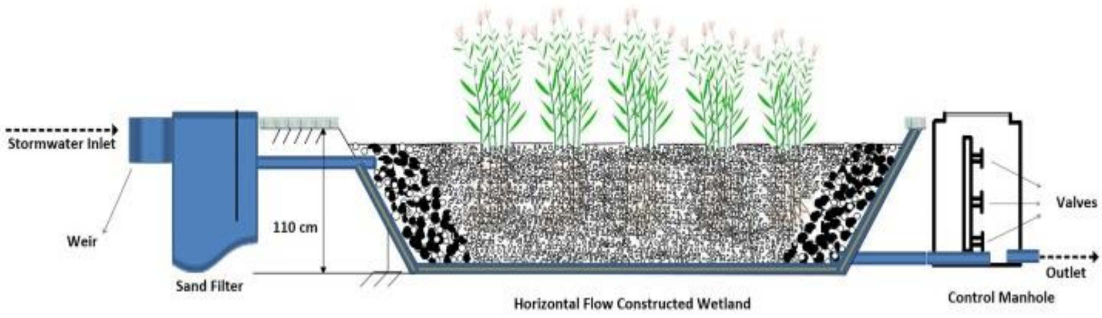

Figure 1. Airport stormwater runoff treatment system (constructed wetland)

A different treatment system design approach is discussed in this study. This approach is based on the period of time during which stormwater runoff that is carried to the system is retained in the treatment system. In this regard, stormwater runoff that reaches the system is retained in a specially designed pond at least for two hours after sand filtration. Just as in the other system, it is considered that the daily heaviest rainfall will enter the system during the first 10 minutes after the onset of rainfall. Required pond volume has been calculated as 20 m^3 accordingly. Dimensions of the system are 3.65 m x 7.30 m x 0.75 m (Width/Length/Height). Both compressed clay with thickness of 10 cm and geo-membrane with thickness of 1.5 mm can be used in order to ensure imperviousness of pond base and slopes. In case of heavy rainfall, wastewater that leaves the system can be discharged into sewage system for further treatment. As the water that would be retained for a long period of time in case of limited water will dry during summer months, waste that accumulates in the bottom in form of cake can be eliminated within the scope of regulation on control of hazardous wastes. New soil must be laid to replace the organic soil that is lost while scraping bottom of the pond. Details of the system are shown on Figure 2.

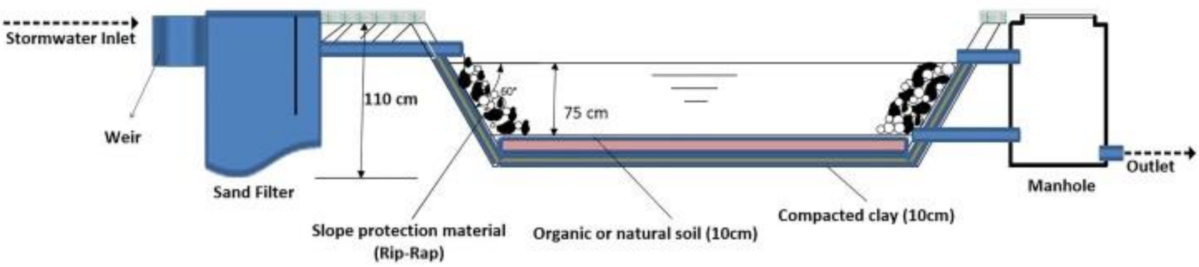

Figure 2. Airport stormwater runoff treatment system (wet/dry pond)

There are different studies conducted specifically for miscellaneous pollutants that are contained in stormwater runoff which originates from airports. In a study conducted with regard to various low-cost treatment systems (Stormwater wet ponds, stormwater wetlands, filtering practices, water quality swales), it has been reported that hydrocarbon removal performance is 62%-85% while metal removal efficiency is 26%-99% (for Cu and Zn) (Winer, 2000). One of other studies addresses the removal of zinc that is highly toxic for aquatic ecosystems in an absorption environment that contains oyster shell fragments and compost and sand mixtures of oyster shell fragments (Long and Zou, 2019). According to this study, it is indicated that 99% of zinc is removed in such absorption environment (Long and Zou, 2019). Materials such as aggregates, obtained following peat and sewage sludge thermal procedure that is named as biological filter, have started to be used recently for treatment of de-icing agents. A study conducted regarding removal of nitrogen compounds through biological filter obtained from sewage sludge showed that while such compounds are removed more efficiently when C/N rate is 0.5 gC/gN under temperature conditions between 0 and 8°C, 5 gC/gN rate yielded better results when the temperature was 25°C (Rodziewicz et al., 2020). Such innovative practices will obviously be implemented more in the future for not only treating airport stormwater runoff but also disposing sewage sludge as they are sustainable models. Aerated constructed wetland system is one of the systems that have started to be used especially in cold climates for treating de-icing agents for the last ten years. These systems are actively aerated in order to increase their treatment efficiency under cold climatic conditions. Nevertheless, the space they occupy has been diminished significantly compared to other conventional constructed wetlands. However, as such aerated systems consume energy, their operational and maintenance costs are much higher than that of other constructed wetland systems. Estimated number of these systems used also for treating de-icing agents is around 500 in the world (Nivala et al., 2020). In a study conducted regarding partitioning and transport of metals on asphalt coated areas such as motorways, parking areas and airports, it is indicated that despite the highest affinity of particle-caused fraction of copper and lead, zinc exhibits different partitioning behavior depending on the area and chemical characteristic of zinc (Gnecco et. al., 2019). In another study conducted with regard to removal of cadmium that is contained in airport stormwater runoff and even the smallest doses of which can cause significant environmental pollution, it is revealed that half of cadmium can be removed successfully by use of sorption that contains sulfur functionalized polymer particles embedded onto the surface of alginate bead (Ko et al., 2018). In one of the limited number of studies carried out to examine effects of airport stormwater runoff in terms of ecotoxicology, *Lemna gibba* and *Aliivibrio fischeri* were used as biological indicators and

50% and 25% inhibition was detected for *L. Gibba* and *A. Fischeri* respectively during winter months (Calvo et al., 2020). One of the pollutants contained in airport stormwater runoff is oil and grease that originates from aircrafts, shuttles and other operations. Such pollutants must be taken into consideration in terms of wastewater management because significant amount of oxygen is required for their biological degradation. In this regard, there are several studies which show that oils can be effectively separated and removed from stormwater runoff (Jia et al., 2018; Velautham et al., 2021). In such studies, it is argued that after the infrastructure required to separate oil and grease from stormwater runoff is established, it would be more effective to treat such water through infiltration basins or constructed wetland systems.

As can be seen, although this study involves constructed wetlands designed on the basis of carbon removal, there are similar studies that will also be effective in removing the toxic pollutants and other compounds mentioned above. Since the systems are modular systems, it is possible to upgrade them in terms of different treatment options as a result of long-term monitoring studies.

4. Conclusions

As airports have large impervious spaces with dense aircraft and shuttle traffic, besides the pollutant generated by these vehicles, pollution caused by de-icing/anti-icing chemical agents and chemical agents used for other purposes must be eliminated. Although there are several alternative methods for elimination, this study focuses on low-cost systems. The most suitable treatment system can be determined based on following factors: the size of each airport and therefore the amount of waste generated; whether there is enough space assigned for treatment or not and, most importantly, at least one-year program for monitoring waste generation volume and pollutant load.

Some wastewater treatment systems that can be recommended according to airport characteristics are given below.

1- If there is an existing wastewater treatment plant near the airport, the initial part of the wastewater, especially from flash precipitation, can be treated in this wastewater treatment system.

2- Since the pollutant load of stormwater runoff varies according to the intensity of the precipitation, it would be beneficial to prefer treatment systems that are more tolerant of sudden loads (Constructed wetland, aerated gravel beds, hybrid systems etc.).

3- The use of aerated gravel beds and similar systems in cold climatic conditions will give more satisfactory treatment results.

4- In case there is sufficient space at or around the airport, systems such as constructed wetland and hybrid constructed wetland can be preferred. Especially for small airports, such systems may be more sustainable treatment options.

5- If the area where the airport is located is in a sensitive basin or if the discharge criteria for the receiving environment are very strict, then advanced treatment systems or systems like aerated gravel beds may be preferred. However, if there is a sufficiently large treatment area, a combined treatment method with other treatment systems can be considered.

Since the systems indicated in this study are recommended for small airports, if the conditions are suitable, it may be applicable to medium and large-sized airports as well.

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