DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DEVELOPMENT OF WATER EFFICIENCY STRATEGY FOR ADNAN MENDERES AIRPORT

by

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İZMİR

DEVELOPMENT OF WATER EFFICIENCY STRATEGY FOR ADNAN MENDERES AIRPORT

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"DEVELOPMENT OF WATER EFFICIENCY STRATEGY FOR ADNAN MENDERES AIRPORT"** completed by **MERVE ÖZLEM VURMAZ** under supervision of **ASSOC. PROF. DR. HÜLYA BOYACIOĞLU** 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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DEVELOPMENT OF WATER EFFICIENCY STRATEGY FOR ADNAN MENDERES AIRPORT

ABSTRACT

The thesis focused on water consumption footprinting and development of water efficiency plan for the Adnan Menderes Airport located in Izmir, Turkey. Airports are facilities having large water consumption, generally for non-potable purposes such as water cooling systems, fire control, cleaning and washing of vehicles, runways and aircrafts and also public uses (WC, food service). Research period covered 12 months and consumption data (obtained from 116 water meters) were analysed for water footprinting. Along a year, Adnan Menderes Airport served to about 12 million passengers and 81 thousand aircrafts. These passengers and aircrafts were served by various services by airport authorities. These services were linked by water consumption directly or indirectly. Total water consumption in the airport was analysed by categorising users under three groups:

- Domestic terminal
- International terminal
- Out of terminals

Annual water consumption was about 436,000 cubic meter per year in total. Results of the footprinting study showed that cooling towers, irrigation, terminal WC and fire system uses accounted high use rated with 26 percent, 23 percent, 20 percent and 7 percent. While water used for WC changed between about 6-8.5 litter per pax, this value was between 1-1.5 litter per pax for food consumption. Therefore passenger based uses was fluctuated between 6.5-10 litter per pax in the airport. This value was below world average rates. Based on this analysis several methods were suggested to minimize water consumption. Among them “training and education of airport staff” was proposed as the most economical solution. Furthermore “improved water consumption monitoring” system could be suggested as applicable method considering economical and physical aspects and should gain priority. Then alternative measures could be chosen based on their economical and physical applicability.

Keywords: Water efficiency, water conservation, water footprint

ADNAN MENDERES HAVALİMANI İÇİN SU VERİMLİLİK STRATEJİSİNİN GELİŞTİRİLMESİ

ÖZ

Çalışma, İzmir Türkiye'de bulunan Adnan Menderes Havalimanı için su kullanım ayak izi ve su verimlik planının geliştirilmesi çalışmasını kapsamaktadır. Havalimanları çok su kullanılan tesislerdir. Genellikle su, soğutma kuleleri, yangın kontrolü, temizlik, araç yıkama, yer yıkama, uçak yıkama ve genel kullanımlar (WC, yemek servisi dâhil) için kullanılmaktadır. Araştırma 12 aylık periyodu kapsamaktadır ve tüketim verileri 116 sayaçtan elde edilerek su ayak izi için analiz edilmiştir. Bir yıl boyunca Adnan Menderes Havalimanı, 12 milyon yolcu ve 81 bin uçağa hizmet vermiştir. Bu yolcular ve uçaklar farklı havalimanı otoritelerinden hizmet almıştır. Bu hizmetler su tüketimi ile doğrudan ya da dolaylı olarak ilişkilidir. Çalışmada havalimanında toplam su tüketimi 3 grupta incelenerek analiz edilmiştir.

- İç hatlar
- Dış hatlar
- Terminallerin dışı

Havalimanında yıllık toplam su tüketimi yaklaşık 436,000 metreküp /yıl'dır. Ayak izi çalışmasının sonuçları, en yüksek kullanım oranlarının; soğutma kuleleri, sulama, terminal tuvaletleri ve yangın kontrol sistemi kullanımlarında sırasıyla yüzde 26, yüzde 23, yüzde 20 ve yüzde 7 olduğunu göstermektedir. Tuvaletler için su kullanımı yolcu başına yaklaşık 6 ile 8.5 litre arasında değişmektedir. Yiyecek hizmeti için bu değer 1-1.5 litredir. Dolayısıyla havalimanında yolcu esaslı kullanım (WC ve yiyecek servis hizmeti dâhil) yolcu başına 6.5 ile 10 litre arasında salınım göstermektedir. Bu değer dünya ortalamasının altındadır. Çalışma sonuçlarına dayanarak su tüketimini en aza indirmek için çeşitli yöntemler önerilmiştir. Bunlar arasında "havalimanı personelinin eğitimi" en ekonomik çözümdür. Ayrıca "gelişmiş su tüketimi izleme" sistemi, ekonomik ve fiziksel koşullar dikkate alındığında uygulanabilir bir yöntemdir ve öncelik kazanmalıdır. Daha sonra, ekonomik ve fiziksel uygulanabilirliklerine dayalı olarak alternatif önlemler seçilebileceği düşünülmektedir.

Anahtar Kelimeler: Su verimliliği, su koruma, su ayak izi

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CHAPTER ONE
INTRODUCTION

Water is limited and less than 1% of water is in the world is accessible (Rozin et al, 2015). In parallel to population growth, global warming and water pollution are threatening future fresh water resources (Longyang, 2019; Manning & Nobles, 2017; Zhang et al, 2017).

Industries consume water a) for domestic purpose (in kitchen and restroom etc.), b) as process water and also c) for non-domestic purposes (cooling water, irrigation etc.) (SFWMD - South Florida Water Management District, 2013). In commercial buildings water usage rate may change between 95 to 520 litter per employee per day (NCDENR - North Carolina Department of Environment and Natural Resources, 2009).

Airport industry is vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry.

Secure and dependable water resources are essential to the successful operation of any airport. Water is needed for maintaining food and hospitality concessions within the airport complex, operating cooling towers and basic amenities within the terminal area, cleaning and maintaining aircraft and rental cars, and maintaining grassed areas and landscapes. Water efficiency efforts are becoming more critical due to following reasons (EWS - European Water Stewardship, 2012; Krop et al, 2016):

- Climatic changes are affecting water availability from year to year
- Increasingly complex regulations are affecting the availability and cost of potable water in the world

- The continued growth and expansion of urban centres are effecting water availability.

The thesis aimed to design “Water Efficiency Plan” for Adnan Menderes Airport” located in Turkey. In this scope firstly water consumption footprinting of the airport has been implemented. Then water efficiency plan was developed. The main target was to determine most water consumed activities/facilities within the airport and propose efficiency plan to minimise these uses. Overall objective was water saving considering climate change effects in near future in this region and also economical aspects.

Water users/facilities were analysed under three categories:

- Domestic terminal
- International terminal
- Out of terminal

Records of 116 water meters located on the water supply line, distribution network were evaluated for these categories separately, and efficiency measures were proposed.

CHAPTER TWO

WATER MANAGEMENT STRATEGIES FOR AIRPORTS IN THE WORLD

On 17 December 1903, Orville Wright flew with his aircraft and then aircrafts were developed. First airport was constructed in 1909 for the purpose of landing, taking off, parking, fuelling and repairing of aircrafts. During World War I, aircrafts are significant for national defence and aviation sector was developed rapidly by involving aircrafts and establishing airports. Some of military airports were converted to civil use also its operations (IATA – International Air Transport Association, 2015).

Today, aviation is the one of the biggest sector that is still expanding and growing up faster than most of other sector in the world. Air transport increases 50% every fifteen years (ACI – Airport Council International - et al, 2017). 3.8 billion passengers used airways annually in 2016 with increasing rate 6.8% from 2015. There are over the 26,000 aircraft in services, 1,400 scheduled airlines and 3,900 airports (ATAG – Air Transport Action Group, 2016).

Environmental concern was started after the 1960s (IATA, 2015). The most common concerns are air pollution (causing climate change) and noise. Furthermore, air quality and local environments, which means biodiversity, wildlife, surface access, airport's waste, airline's waste, water quality and water consumption, are also affected directly (CAA – Civil Aviation Authority, 2017).

Climate Change: Aircrafts emit CO_2, NO_x, soot aerosols, and water vapours (CAA, 2017) that contribute the mechanism of climate change directly (Cottis, 2001). Nonetheless, airport's emission resources are; boiler, furnaces, burners, turbines, heaters, incinerators, engines, firefighting exercises, flares automobiles (airside/landside), trucks, employee buses, ground power units, business travel, onsite waste and wastewater management, leaks from plants particularly refrigerants, fire suppression CO_2, methane, fuel tanks, emissions from purchased electricity, heating, cooling (Ozdemir, 2013).

Noise Pollution: Numerous airports are source of noise pollution caused by aircrafts when they are slowing down after landing, and taking off (Sondakh et al, 2014).

Air quality: Poor air quality has impact on health and vegetation and ecosystem. In addition to CO_2, and NO_x, particulate matters (PM), poly aromatic hydrocarbons (PAHs), benzene, carbon monoxide (CO), 1, 3 –butadiene are originated from airports (CAA, 2017).

3.8 billion passengers flew and 62,7 billion jobs are supported by aviation sector in the world (ATAG, 2016). Airport users divided by four groups: passengers, employees, visitors and suppliers (Neufville and Odini, 2013). Emissions by their transport choices to the airports have a significant effect on air quality (CAA, 2017).

Biodiversity and wild life: Airport operators attempt to get the birds away for flight safety (Hoon and Buurma, 2000). On the other hand, these areas are the good opportunity to support biodiversity and wild life (with no access by people) (CAA, 2017).

Airport's waste: Airports generate oil, fuel, hydraulic fluid, sanitary sewage and de-icing chemicals waste (IATA, 2015). Wastes are grouped under several classes as: domestic solid waste, construction and demolition waste (C&D), green waste, food waste, waste from aircraft flights (deplaned waste), lavatory waste, spill clean-up, remediation waste and hazardous material (FAA – Federal Aviation Administration -, 2013).

Water quality monitoring is important to prevent water-borne disease (WHO – World Health Organisation- , 2010) and protect environment (all aquatic life, vegetation and animals). Airport activities affect water quality with fuel leaks, spillage and de-icing fluids if not controlled (CAA, 2017). De-icing materials (mixture of water with anti-freeze chemicals) are used for removing ice, snow and frost from surface of aircrafts just before taking off. Salt, various solid or liquid anti-freeze chemicals are also used to remove or prevent icing or other forms of ice on the movement area and road (IATA, 2015).

Glycol, which is a colourless and mild odour liquid. It is belonged to alcohol family in the organic compound and used for de-icing (Ozdemir, 2013; ICF, 2007).

2.1 Water Usage in Airports

Airport services provide water to the aircraft. Water in general is also used for other activities/services/facilities. For instance;

- ✓ Airfield (including runways, taxiways, platforms and green areas in between)
- ✓ Aviation schools and dormitories,
- ✓ Bus Stations
- ✓ Cantinas
- ✓ Caterings,
- ✓ Cooling and heating plants, (HVAC – Heating, ventilation, and air conditioning- systems for buildings)
- ✓ Fire and police station,
- ✓ Food services,
- ✓ Freight / Cargo facilities,
- ✓ Fuel depot
- ✓ General Aviation
- ✓ Governmental buildings,
- ✓ Ground transportation,
- ✓ Hangars and airplane maintenance
- ✓ Military services,
- ✓ Oil companies,
- ✓ Parking,
- ✓ Railway Stations
- ✓ Rent-a-car services,
- ✓ Special operations buildings
- ✓ Surface vehicles maintenance
- ✓ Taxi Stands
- ✓ Tenants etc.
- ✓ Terminals and piers

- ✓ Wastewater Treatment Plants
- ✓ Water Supply Infrastructure Systems (including drinking water treatment facilities) etc. (EWS, 2012; Krop et al, 2016)

These water audits are depicted in Figure 2.1

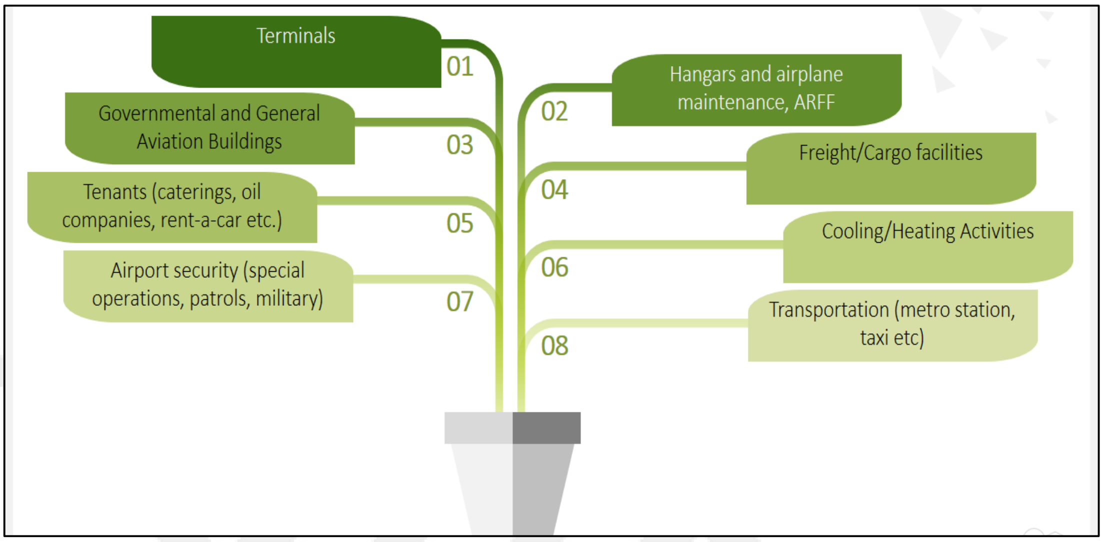

Figure 2.1 Water audits at airports

Every airport has different water consumers. For instance; Santa Monica Airport has a local college and automobile design company (Krop et al, 2016).

Water end-uses in Airports: Systematically, water audit is a kind of research for all water end uses with fixtures, appliances, equipment and practices at water research area (SFWMD, 2013). In the airports in auditing studies facility based water end uses which are presented in Table 2.1 are taken into consideration (Krop et al, 2016)

Table 2.1 Water End-Uses (Krop et al, 2016)

Facility	**Example of End Uses**
Terminals	Toilets, urinals, bathroom and kitchen faucets, dishwashers
Office Buildings	Window cleaning, Interior plant watering, toilets, urinals, faucets
Rental Car Centre	Fleet vehicle washing, outdoor irrigation
Ground Transportation	Vehicle washing
Parking	Snow removal, street cleaning

Table 2.1 continues

Facility	Example of End Uses
Hotels	Toilets, showers, ice machines, swimming pools, spas, laundry
Central Heating / Cooling Plant	Boiler, cooling
Maintenance and Services	Runway rubber removal, employee break rooms and restrooms
Airlines / Aircrafts / Cargo	Aircraft cleaning, on-board aircraft water, de-icing
Fire and Police Stations	Fleet vehicle washing, fire suppression

This table does not mean that these activities and facilities should be in all airports. Because every airport is special and unique. Every airport has regional climate, different size and type of airport, local, regional, state and federal water laws, water conservation regulations, aviation activities, atmospheric conditions, topography, environment (Krop et al, 2016; Ozdemir, 2013). However, every airport has to have same facilities. For instance; hangars, technical block & control towers, administrative buildings/ offices complexes, Airports Authority & Military Services Residential complexes, fire stations, medical centres, maintenance technic workshops and others (IATA, 2015).

Water usage in aircrafts: PWMP (a Potable Water Management Plan) is important for aircraft's Safety Management Systems (SMS). Hence, airports have to provide potable water with water systems on-board aircraft (Health Canada, 2013). Potable water is consumed in various ways on-board at commercial transport aircrafts (including direct human usage). Water is needed for preparation of hot and cold beverages, reconstitution of dehydrated foods, cold water taps, reconstitution and ingestion of medications, cleaning of utensils and working areas, preparation of hot, moist towels, on-board showering facilities, emergency medical use in the aircrafts (WHO, 2009).

2.2 Water sources in Airports

Airports need a dependable and secure water supply for their operations (Smith, 2011). Therefore, water suppliers are important for them. Airports have mainly 3 type of suppliers. These are; municipal water networks, water sub-supplier companies, their own water supply that can be groundwater or surface water or alternative water resources (EWS, 2012). Surface water and ground water are the blue water resources (Hoekstra et al, 2009).

Surface water: Surface water sources are streams, rivers, lakes, human-made impoundments (dams), springs, shallow wells, well drilled next to the streams or rivers, rain catchments, muskeg and tundra pond. These sources can be polluted easily with anthropogenic effects and can evaporate.

Groundwater: Groundwater is obtained from wells and underground springs. Groundwater cannot be polluted easily in comparison to surface water. Their quality is stable and microbial contamination is less. Nonetheless, if they were polluted once, it could be difficult to clean. Furthermore, abstraction of groundwater is harder than surface water.

Alternative Water Supplies: Airports cannot ignore the alternative sources particularly in water-stressed area (EWS, 2012). These are harvested rainwater and run-off, treated seawater and brackish water, recycled water from cooling towers, grey-water.

Rain water and Run-off: Airports are suitable for rainwater collecting and harvesting because of having large roof areas, bird control programs which reduce the pollution and height of airfield vegetation managements shrink the microbial contamination risk and access the water storage tanks (Neto et al, 2012). The advantage of rainwater harvesting is that a) it is independent from centralized system b) conserves the water and energy c) has less risk about local erosion and flooding. Nonetheless, rainwater falls can be effected by air pollution and rainwater is a soft water that is an advantage for cooling tower but disadvantage for water usage for detergents and soap. There can be different applications for water harvesting such as:

storing rainwater for direct use, recharging groundwater aquifers from roof top run-off, recharging groundwater aquifers with run-off from ground area (IRICEN, 2006). At the airports, rainwater and storm-water used for landscape irrigation, cooling tower make-up water, car wash facilities, wash-down water, can be mixed cooling tower bleed-off water or brackish water, other (ch2m, 2017). There are many examples of rainwater harvesting in the world.

In Schiphol Airport, non-potable water which was collected from roofs reduced water bills by 58% (Kuller et al., 2016).

Hartsfield-Jackson Atlanta International Airport has 25,000 water reclamation boxes for collecting rainwater and there are 3 cisterns with the capacity of 9,463.5 litter (ATL – Hartsfield Jackson Atlanta International Airport, 2011).

The San Diego International Airport worked for reusing and capturing runoff-water for non-potable purposes and Melbourne International Airport was started to collect and reuse storm-water in 2012. Austin-Bergstrom International Airport established rainwater catchment system in Austin, Texas (ch2m, 2017).

Tancredo Neves International Airport was storing rainwater for direct use (Neto et al, 2012) and Changi Airport consumed rainwater for fire-fighting drills and restrooms (UNEP – United Nation Environmental Protection –, 2002)

Seawater and Brackish water: In much water-short areas, water utilities are looking for new sources for supply like treated sea water (WRF – Water Research Foundation-, 2010). The advantage of sea-water and brackish water is that there is a huge amount but on the other hand it is too expensive right now. There are some methods for sea-water treatment. These are membrane desalination; reverse osmosis (RO), and thermal desalination; multi-stage flash evaporation (MSF) and multi-effect distillation (MED).

The King Abdulaziz International Airport installed desalination plant with total capacity of 30,000 m^3 per day in 2010 (Public Disclosure Authorized, 2013).

Hong Kong International Airport was consuming 375,000 m^3 seawater per day. In the airport 7,300 m^3 water per day was used for toilets flushing and 2% of which were sea water (Leung et al, 2014).

Recycled water from cooling towers: Cooling tower is one of the most important water consumption area in airports. Reduction of operational water consumption in cooling towers can be achieved by following measures (Bradwell et al, 2009).

- Shrinking the cooling load and optimizing tower or system controls
- Improvement cycle concentration and reducing bleed water volume
- Precaution about drifts
- Prevention of overflows, leaks, windage and splash out
- Maintaining all equipment including backwashing and system cleaning
- Training the employee who operate cooling towers

Cooling tower water end use can be classified under 6 categories. These are make-up water, wingage -splash out, evaporation, drift, leaks - overflows and bleed (Bradwell et al, 2009).

Grey water is wastewater which is produced by domestic purpose. For instance; sinks and faucets, showers and baths, toilets and urinals, washing machines, dishwashers, waste disposal unit and food steamers etc. Grey water can save money and fresh-water amount, contain nutrients for plants and save money from sewage bills, if there is. Nevertheless, it can cause of spreading disease, can cause of odours and can damage plants even soil if not well controlled.

2.3 Water Use Footprinting in Airports

Every airport expresses their water consumption in different ways. For instance;

- Total water consumption (per year/m^3/passenger) or (per 1000 passengers)
- Total potable water used in public areas per passenger
- Wastewater discharged per 1000 passengers
- Yearly trends in wastewater COD in tonnes of COD

- Indicators of water quality of wastewater discharged at outlet from wastewater and contaminated rain water treatment plants (kg)
- Consumption of drinking water (m^3)
- Quantity of water discharged
- Quantity of ground water abstracted (GRI, 2009)

In Table 2.2: Annual total water consumptions of various airports in the world and in Table 2.3 water consumption rate per passenger are presented.

Table 2.2 Annual total water consumption (m^3 per year)

Airports	**m^3 in total**	**Reference**
Steward International Airport	5,824,287	After SWF, 2017
Hamad International Airport	4,789,058	Qatar Airways, 2017
Heathrow Airport	2,220,772	LHR, 2017
San Francisco Airport	1,923,451	After SFO, 2015
Leonardo da Vinci – Fiumicino Airport	1,903,000	ADR, 2016
Vancouver International Airport	1,222,265	YVR, 2018
Hartsfield Atlanta Jackson International Airport	1,148,446	After ATL, 2011
Madrid Barajas Airport	1,133,250	AENA, 2016
Munich Airport	1,050,791	MUC, 2017
Gatwick Airport	736,772	GAL, 2017
Istanbul Ataturk Airport	524,000	TAV Airports, 2011
Osaka International Airport	322,275	ITM, 2017
Auckland Airport	292,543	AKL, 2016
Brussels Airport	231,841	BRU, 2016
Malta International Airport	195,407	MLA,2018
Ankara Esenboga Airport	168,600	TAV Airports, 2011
Izmir Adnan Menderes Airport	145,200	TAV Airports, 2011
Ciampino Airport	144,000	ADR, 2016
Bristol Airport	59,820	BRS, 2015

Table 2.3 Total water consumption per passenger

Airports	Passenger per litter	Reference
Bristol Airport	9.4	BRS, 2015
Brussels Airport	10.2	BRU, 2016
Amsterdam Airport	13.3	Schiphol Group, 2014
Hong Kong International Airport	15.6	HKIA, 2013
Vinci Airports	16.8	Vinci Airports, 2017
Gatwick Airport	17.08	GAL, 2017
Glasgow Airport	19.7	GLA, 2015
Frankfurt Airport	21.7	Fraport, 2017
Porto Alegra Airport	23	Carvalho et al, 2013
Salvador Airport	23	Carvalho et al, 2013
Madrid Barajas Airport	23.09	MAD, 2011
Recife Airport	24	Carvalho et al, 2013
Atlanta International Airport	27.67	After ATL, 2016
Heathrow Airport	29	LHR, 2017
Sydney Airport	31	Smith, 2013
Stansted Airport	32.2	BAA, 2007
San Francisco Airport	42	After SFO, 2015
Lisbon Airport	43	Carvalho et al, 2013

Some airports expressed their consumption as 1000 m^3 per 1000 passenger in the reports (Table 2.4)

Table 2.4 Total water consumption per 1000 passengers

Airports	1000 m^3 per 1000 passenger	Reference
Izmir Adnan Menderes Airport	0.019	TAV Airports, 2013
Ankara Esenboga Airport	0.021	TAV Airports, 2013
Istanbul Ataturk Airport	0.016	TAV Airports, 2013

Water discharge rates of some airports are also presented in Table 2.5.

Table 2.5 Total wastewater discharge1000 m^3 per year

Airports	1000 m^3 per year	Reference
Istanbul Ataturk Airport	533.50	TAV Airports, 2013
Ankara Esenboga Airport	283.00	TAV Airports, 2013
Izmir Adnan Menderes Airport	99.55	TAV Airports, 2013

2.4 Airport Water Conservation

Airports that develop the "Water Efficiency Strategies" which is also known "Water Footprint" should research basically how much, where, how and what purpose of water, water is being used. Afterwards water footprint is finding the solution about how can we minimize water consumption (Krop et al, 2016).

When airports want to develop "Water Efficiency Program", the reasons of the motivations are water scarcity, budget, management priorities and stakeholder supports and also there are some advantages in addition these motivations. These are a) decreasing the wastewater amount which means indirectly reduction of carbon dioxide which is important for Airport's Carbon Footprint, b) reduce cost about the water and energy with water efficiency and energy efficiency in operation, maintenances, c) decrease the risks according to the water scarcity with water saving, d) increase the prestige and proof the leadership, achieve the opportunity about LEED gold/platinum, improve sustainability with positively effecting on environment and public health, e) reduce environmental impacts, access sustainable future water supply, get ISO 14046 Environmental management – Water footprint – Principles, requirements and guidelines, f) plan the water and drought management (NRDC, 2009; Krop et al, 2016).

Different water end use efficient levels are depending on the type/age of fixtures and equipment (Krop et al, 2016). Water consumptions based on water efficiency level of used equipment are presented in Table.2 6.

Table 2.6 Water consumptions based on water efficiency level of used equipment (after Krop et al, 2016)

Use	**Efficiency Level**			**Efficiency Description**	**Unit**
	Max	**Average**	**Min**		
Toilets	4.85	6.06	13.25	L/flush	Users
Urinals	0.47	3.79	7.57	L/flush	Users
Faucets	1.89	3.79	7.57	L/minute	Users /Meal Served
Showers	3.79	7.57	11.36	L/minute	Users
Pre-rinse spray valves	4.85	7.57	11.36	L/minute	Meal Served
Dishwashers	3.79	9.46	17.03	L/rack	Meal Served
Ice machines	1.00	2.09	12.52	L/ kg ice	Meal Served
Boilers	189.27	283.91	378.54	L/ day	Number of Boilers
Laundry	12.52	20.86	29.21	L/ kg	Users
Training	18.93	28.39	37.85	L/unit	Training Events
Pavement cleaning	18.93	28.39	37.85	L/unit	Users/ Vehicles/ Rentals
Vehicle washing	113.56	151.42	302.83	L/unit	Rentals/Vehicles
Snow removal	18.93	28.39	37.85	L/flight	Flights
Fleet vehicle washing	18.93	28.39	37.85	L/flight	Flights
Runway rubber removal	18.93	28.39	37.85	L/flight	Flights
Aircraft cleaning	18.93	28.39	37.85	L/flight	Flights
On-board aircraft water	18.93	28.39	37.85	L/flight	Flights
De-icing	18.93	37.85	75.71	L/flight	Flights

Water Conservation methods could be: (NYSDEC, 1998)

1. Metering
2. Pressure reductions (service and system)
3. Pricing (uniform or inclining commodity rates, seasonal rates)
4. Outdoor Use (restrictions, efficient landscape design, scheduled irrigation, efficient irrigation systems, tensiometers)
5. Industrial reuse/recycling
6. Leak detection and repair (within water supply system, within costumers' premises)
7. Plumping retrofit (low-flow showerheads, toilet-tank-displacement, pipe insulation, faucet aerators)
8. Moderate plumbing code (enforcement existing state code)
9. Advanced plumbing code
10. Public education/information

2.5 Methodology to Develop Water Management Strategies in Airports

Airports are developing water efficiency strategies as follow (EWS, 2012, Krop, 2016);

- Definition of scopes
- Definition of area of influence
- Water balance
- Preparation
- Generating water footprint baseline
    - ★ Data collection
        - → How much water-meters exist
        - → Water-meters location
        - → Water bills
        - → Water volume
        - → Water distribution systems
        - → Leak control programs
        - → A map of airport campus

        - → Special use designation (landscape irrigation, cooling system, fire protection)
    - ★ Researching
        - → Water end uses
    - ★ Calculating
        - → Annual average
        - → Annual and seasonal variation
- Defining targets
- Evaluating and Choosing Water Efficiency Measures and Strategies
    - ★ Finding which efficiency measures are feasible technically
    - ★ A detailed discussion with maintenance staffs, management, contractors and depending on situation manufacturers
    - ★ Choosing conservation measures depending on program goals that typical criteria are applicability, effective and feasible.
    - ★ The evaluation of water efficiency programs about alternative measures and economic feasibility
    - ★ Cost-benefit analysis
        - ☞ Identifying and measuring the costs
        - ☞ Identifying and measuring the benefits
        - ☞ Discount future costs and benefits
        - ☞ Calculating the impacts
        - ☞ Analysing the sensitivity of results
- Design a program
    - ★ Meet with Water Efficiency Management Team
    - ★ Prepare Action Plan
    - ★ Conceive Financial Resources
    - ★ Employee and Tenant Education and Participation
- Applying the Water Efficiency Program
    - ★ Design the successful strategy
        - ☞ Evaluating Water Efficiency Priorities
        - ☞ Defining resource adequacy
        - ☞ Developing implementation schedule

- ★ Developing Employee Training
- ★ Produce Communication Strategies
  - ☞ Developing a mission statement
  - ☞ Brainstorm communication channels
  - ☞ Developing a communication plan
    - ❖ Summarize the objective and goals
    - ❖ Identifying target audiences relevant
    - ❖ Progress the message
    - ❖ Set and distribute the message in formats
    - ❖ Assessing the outreach performance
  - ☞ Brand the program
  - ☞ Craft the messaging
  - ☞ Package and distribute
  - ☞ Maintaining, Assessing and Revising the Water Efficiency Program

2.6 Airport Water Stakeholders

Airport stakeholders that are influenced by efficiency program are as follow:

- Passengers
- Business, Commerce, Tourism, Arts, Sports, and Education Organizations
- Air carriers
- General Aviation Users
  - → Air taxi operators
  - → Corporate-executive transportation
  - → Flight instruction
  - → Aircraft rental
  - → Aerial application
  - → Aerial observation
  - → Business
  - → Pleasure
- Airport Organization

- Investors and Bond-holders
- Service Providers
    - → Supply of aviation fuel and oil
    - → Baggage handling and sorting
    - → Loading and unloading of aircraft
    - → Interior cleaning of aircraft
    - → Toilet and water service
    - → Passenger transport to/from remote stands
    - → Catering transport
    - → Routine inspection and maintenance of aircraft at the stands
    - → Aircraft starting, marshalling, and parking
    - → Aircraft de-icing
    - → Passenger handling (e.g. ticketing and check-in)
    - → Cargo and mail handling
    - → Information services
    - → Preparation of handling and load-control documents
    - → Supervisory or administrative duties
- Employees
- Federal Government
    - → Transportation Security Administration
    - → Customs and Border Protection (CBP)
- Local Government
- Communities Affected by Airport Operations
- Non-Governmental Organizations (NGO's)
- Parking Operation and Transportation Providers
- Airport Suppliers (Schaar, 2010)

2.7 Examples on Water Conservation Measures

Some precautions on water conservation are summarised below

Upgrading fixtures

a. Install Automatic Sensors on Faucets to conserve water
b. Install waterless urinals
c. Install pressure-assisted toilets to conserve water usage
d. Install low-flow plumbing fixtures in facilities
e. Use high pressure nozzles in car washes and for aircraft washing
f. High pressure nozzles for aircrafts/trolleys/pans etc. washing
g. Water conserving aerators
h. Shower heads flow rate reduction
i. Low flow plumbing fixtures
j. Changing pre-spray valves

Minimisation of water for irrigation

a. Reduce potable water used in irrigation systems by limiting irrigation frequency and duration
b. Use synthetic grass in landscaping
c. Irrigation flow-meters
d. Reduction of head island effects
e. Drip systems for irrigation
f. Sub-surface irrigation
g. Garden bed re-mulched
h. Wetting agent usage
i. Water storage crystals usage
j. Rubber stabilizer usage
k. Garden beds weeded
l. Regularly aerated lawns

Recycle and Reuse water

a. Implement a water reclamation system in airport car/aircraft wash area
b. Recycle used non-potable water
c. Water recycle system
d. Water usage from alternative sources

Water efficiency for cooling towers

a. Reduce bleed water
b. Changing chillers (McGormley et al, 2011; GAL, 2017; ATL, 2011; CBR, 2009; CBR, 2014; NFTA, 2011)

2.8 Examples of Water Conservation Activities in Airports in the World

Buffalo Niagara International Airport (BNIA) in Canada consumes water for irrigation; aircraft washing; terminal building activities; fire training exercises; chillers; tenants, which use water for irrigation, building activities and vehicle/equipment washing; and BNIA operations. BNIA discovered inefficient water usage in Airport's area then determined how much water consume by these end-use activities. After that, BNIA found improvements and their pay-back periods (NFTA, 2011).

BNIA discovered most of the water consumption was in Restrooms which consisted toilets, sinks and urinals. Then, BNIA was aware of new technological development about water efficiency returns quickly. They invested waterless urinals; reduced consumption per flush, used grey-water for irrigation / toilets/urinals and installed irrigation flow-meters and readers. Pay-back period for waterless urinals and water-conserving aerators was 18 months (NFTA, 2011).

Efficiency gain after prevention measures are presented in Table 2.7.

Table 2.7 Buffalo Niagara International Airport water efficiency applications

Amount	**Consumption (Litter)**	**After (Litter)**	**Efficiency Gain**	**Conversion**
105 Toilets	6.06	3.03	50%	6.06 to 3.03 L/flush
37 Urinals	3.79	0.00	100%	3.79 to 0 L/flush
95 Sinks	5.68	1.25	80%	5.69 to 1.25 L/minute

Canberra Airport, in Australia started to implement Water Management plan on February 2009. Water Management Plan divided into categories for storm water, water quality, water conservation, groundwater, wastewater and monitoring (CBR, 2009). Water was mainly used consumed by firefighting purposes, car washing facilities, cooling towers, amenities in buildings and irrigation (CBR, 2014).

New terminal was fed by treated harvested rainwater. Similarly, groundwater and rainwater used for irrigation Canberra Airport had two state of the art water recycling system. Their water efficiency program aimed to a) reduce the Airport demand on potable water supply b) reuse subterranean water from building basement (CBR, 2014). In the scope of the program, artificial grass was used, water users were regularly educated, drip system for irrigation was used, garden beds were re-mulched, aqua water recycling system was installed, water storage crystals were used for landscaping, rubber stabilizer was used on high traffic lawns, wastewater treatment effluent was reused (CBR, 2009), water loss was minimised, garden beds were weeded, wetting agents were used to aid with water penetration, rainwater was harvested, water efficient cooling towers were installed, waterless urinals were used (CBR, 2014).

Aqua water recycling system could treat 100,000 litters of wastewater every day and reduced daily potable water consumption from 15 – 20 to 5 litter per person (CBR, 2009). For rainwater collection, Canberra Airport installed two 650,000 litre tanks that fed toilet flushing and irrigation (CBR, 2014). Sub-surface irrigation system reduced water 30 – 40% of water (CBR, 2009).

Hartsfield – Jackson Atlanta International Airport (ATL) mainly consumed water for restrooms, concessions, cooling towers, chillers and landscaping. Total water consumption from 2008 to 2010 was, 22 to 26 litter per passenger. They invested to

630 toilets and this reduced 6 litter per flush to 4.8 litter in 2008. Similarly, 1200 urinals reduced 3.8 litter per flush to 1.9 litter per flush in 2008. T-CUP chillers were replaced two electric chillers in 2009, Reclaim Wash Water (RWW) was designed again for 80% recovery of water. ATL set up 3 water cisterns which had the capacity of 9.5 m^3 for rain water harvesting. Water-loss was monitored and identified leaks was repaired regularly. Indoor and outdoor water use was monitored regularly. Energy Star appliance was upgraded. High pressure pre-wash sprayers (save up 45% of water) were installed. Water audits were conducted yearly. Bleed off water in cooling towers was reduced. Use of harvested rainwater was increased. Storm water management system was designed for all buildings. Reflective materials for pavements, roads, parking lots, side walkers and plazas to reduce urban “heat island” effect was used (ATL, 2011).

Gatwick Airport (GAL), England consumed water mainly for passenger toilets, washing, cleaning, jetting, irrigation, process cooling, food and beverage outlets, car hire, hotels, offices and cargo.

Water consumption ratio and results of management plan is given in Table 2.8.

Table 2.8 Gatwick airport water efficiency plan outcomes (GAL, 2017)

	2010	**2014**	**2015**	**2016**
Water consumption (m^3)	947,067	671,428	689,922	736,772
Water consumption – Cumulative % change on 2010 baseline of 974,067 m^3 (%)	---	-31.1%	-29.2%	-24.4%
Water consumption per passengers (litres)	31.07	17.61	17.13	17.08

Rainwater harvesting on site was not included in this table. GAL’s target was 20% water consumption reduction against the 2010 baseline. In 2016, their water consumption reduction was 24.4%. So GAL changed their target to 25% from 2020. Rainwater harvesting project was started in 2014, regularly leak control was made (GAL, 2017).

Other Airports

Lauderdale Airport invested to change bathroom fixtures. This saved water 163,000 m^3 and with this investment, 281,000$ was saved financially (Hitz, 2015). 41% of water was provided by sea water in Hong Kong International Airport and this investment saved 500,000$ per year (Carvalho et al, 2013). Sydney Airport has saved approximately 550 m^3 per day water with water recycled plants since 2009 (SYD, 2013).

CHAPTER THREE
DEVELOPMENT OF WATER EFFICIENCY STRATEGIES FOR ADNAN MENDERES AIRPORT

3.1 Description of Airport

Adnan Menderes Airport is located on 14 km southwest of Izmir in Turkey with IATA airport code ADB and ICAO airport code LTBJ. It comprises 4 terminals namely domestic, International, VIP and CIP. The passenger capacity is 33,000 per day and increasing nearly 6% yearly.

The region has Mediterranean climate that is hot in summer (temperature is often above 30^{o}C) and mild in winters. The lowest, highest and annual average temperatures are -8.6^{o}C, 43.2 ^{o}C and 17.5 ^{o}C. Relative humidity is around 61% and total average precipitation is 695.2 kg/m^2.

Monthly terminal passenger capacities and number of flights as of 2016-2017 are presented in Table 3.1. From March 2016 to February 2017 Adnan Menderes Airport served to about 12 million passengers and 81 thousand aircrafts. These passengers and aircrafts are served by various services by airport authorities. These services are linked by water consumption directly or indirectly.

Table 3.1 Monthly terminal passenger capacities and number of flights (DHMI, 2018)

	Passenger			Aircraft		
	Domestic	**International**	**Total**	**Domestic**	**International**	**Total**
March	792,962	117,422	910,384	5292	996	6288
April	814,659	136,144	950,803	5169	1195	6364
May	873,803	188,190	1,061,993	5510	1425	6935
June	813,950	192,792	1,006,742	5270	1593	6863
July	825,257	305,005	1,130,262	5473	2404	7877
August	894,152	323,756	1,217,908	5492	2396	7888
September	827,882	260,469	1,088,351	5400	2023	7423
October	856,320	206,113	1,062,433	5582	1608	7190
November	831,378	94,264	925,642	5382	722	6104
December	820,920	96,878	917,798	5488	734	6222
January	800,479	89,773	890,252	5218	693	5911
February	764,176	80,199	844,375	5087	628	5715
Total	9,915,938	2,091,005	12,006,943	64,363	16,417	80,780

Adnan Menderes Airport is growing up year by year in Aviation Sector. In parallel to increase in number of passenger water demand will also increase. Therefore, authorities have to develop water efficiency plans to minimise water demand and environmental impacts.

3.2 Water End Users in the Airport

Total water consumption in the airport was analysed by categorising users under three groups:

- Domestic terminal
- International terminal
- Out of terminals

Domestic Terminal

Domestic Terminal is located on 185,000 m^2 area and has approximately 27,000 passengers per day. These passengers are consuming water in restrooms, praying rooms directly and food services directly and indirectly.

In Domestic Terminal there are companies: cafeterias, restaurants, cafeterias restrooms, coffee and tea shops, canteens, fast food restaurants and personnel cafeterias. In the thesis these places were grouped under “Domestic terminal private sector”.

Water end-uses in private sector are:

- Water use for food preparation
- Kitchen faucets
- Vegetable washing
- Bidet nozzle
- Urinals
- Cleaning
- Coffee machines
- Dishwashers
- Teapot
- Faucets
- Pre-washing
- Toilet

“Water use for food preparation” is just available at 2 restaurants (soup preparation etc.). They mainly consume water for vegetable washing. Bidet nozzles, toilets and faucets are water use points in restrooms. All the private sectors with water meters have dishwashers except fast food restaurants and all of them rinse their dirty dishes before putting the dishwasher. There are 3 types of coffee machines; Turkish coffees machine, espresso and derivatives machine that use coffee seeds and filter coffee machine. Every 2 hours, teapots are refreshed to increase quality of tea. Furthermore, there are hairdresser, pharmacy, medical services, airlines desks, rent-a-car desks, lounge services and tourism agencies desk without water meters due to less consumption rates.

Private sector group also a has hotel located between domestic and international terminals. Water is supplied from domestic terminal. In the hotel there is no kitchen. Food and beverage are supplied by Airport Food Services. All the rooms have restrooms which have bidet nozzles, faucets, toilets and showers and also there are restrooms for personnel usage. Ice machines are available. Interior plants are watered once or twice in a week depending on needs.

In summary water end-uses can be grouped in the hotels as:

- Bidet nozzles
- Faucets
- Cleaning
- Ice machine
- Interior plant watering
- Shower
- Toilets
- Washing machine

Airport Food Service serves food to passengers and also airport staff (main meals, soups, desserts, appetizers, sandwiches, cupcakes, snacks etc. except fast food). Food safety and nutritional standards are very important and everyday food quality is controlled by authorities regularly. Dishwashers, basket washing machines, cauldron washing machines, pan washing machines and vegetable washing machines are water consuming equipment. Dirty dishes are pre-washed before putting into the machine. For personnel usage, there are restrooms which have urinals, toilets, bidet nozzles and faucets. Most of kitchen personnel take shower after their shift. Water consuming activities/equipment at this service are:

- Food preparation
- Vegetable washing
- Basket washing
- Bidet nozzle
- Cauldron washing
- Cleaning
- Dishwashers
- Faucets

- Pan washing
- Pre-rinse spray valves
- Showers
- Kitchen faucets
- Toilets
- Urinals

Domestic terminal passenger based end uses can be classified as:

- Urinals
- Toilets
- Faucets
- Bidet nozzle

Since car parks have toilets they are also considered as water consuming place.

In domestic terminal, there are heat pump system, rainwater harvesting systems, grey water reuse system, solar collectors and trigeneration plants. Except trigeneration plants, these technologies are of plot scale. Therefore, water consumption is not affected by them.

Since water consumption at VIP and CIP terminals are considerably low they were evaluated under this group.

International Terminal

International Terminal covers 107,666 m^2 area and has approximately 6,000 passengers per day. These passengers are consuming water in restrooms, praying rooms directly and in food services that are coffees sit down and take away restaurants directly/ indirectly.

International Terminal Private Sector, water consumption areas are cafeterias, restaurants, cafeterias restrooms, coffee and tea shops, canteens, fast food restaurants and personnel cafeterias same as the Domestic Terminal. Some restaurants are consuming water for vegetable washing. Bidet nozzles, toilets and faucets are water consumption points in the restrooms. All the private sectors with water meters have dishwashers except fast food restaurants and all of them rinse their dirty dishes before putting the dishwasher. There are 3 types of coffee machines; Turkish coffees machine, espresso and derivatives machine that use coffee seeds and filter coffee machine. Every 2 hours, teapots are refreshing because of increasing quality of tea. Except these consumption, there are airlines desks, rent-a-car desks, lounge services, souvenir shops, bookstore and tourism agencies desk without water meters the reason of less consumption. Water consuming activities/equipment at this terminal are:

- Bidet nozzle
- Cleaning
- Coffee machines
- Dishwashers
- Faucets
- Ice machine
- Pre-washing
- Kitchen faucets
- Teapot
- Toilet
- Vegetable washing

Water end use points at car parks are restrooms. In the Airport, there is no car washing activities because it is located in the water protection zone of Tahtali Reservoir.

Out of Terminal

General Directorate of State Airports Authority (SAA) which is called DHMI manages and controls all airports / their activities (Civil Aviation Activities, Ground Services, Air Traffic Control Services, Air Navigation Systems), and airspace in Turkey. In the Adnan Menderes Airport, it has 8 building that are consuming water for domestic purposes (cleaning, kitchen activities, restrooms). However, 2 of them have also additional activities like, runaway rubber removal, schoerling, snow removal and street sweeper. Runaway rubber removal aims removing tire tracks in apron. This mechanical vehicle uses water with high pressure. These data obtained with water consumption questionnaire for this research.

Snow removal is an activity that aim is removing the snow in apron in snowy day. There was only one snowy in January 2017. So this can be ignored activity considering water consumption.

Street sweeper is used for street cleaning in the airport is consuming water for washing the streets.

Water consumption activities are listed in below:

- Cleaning
- Bidet nozzles
- Faucets
- Interior plants watering
- Irrigation
- Praying room
- Runaway rubber removal
- Schoerling
- Showers
- Snow removal
- Street sweeper
- Teapot
- Toilets
- Urinals
- Washing up

Terminal Operator has won the tender from SAA (DHMI) for operating in Adnan Menderes Airport. Terminal operator is responsible for daily operations and their management except airside operations, aircraft and apron management issues. Terminal operator has 5 buildings in out of terminal area. All of the buildings are consuming water domestic purposes. Since these consumption is considerably low compared to other activities, most of Terminal Operator buildings don’t have their own water meters. Basin cleaning and weir cleaning activities are available in Wastewater

Treatment Plants. These data obtained with water consumption questionnaire for this research.

There are 5 Governmental Buildings belonging to custom, patrol, special operations, gendarmerie, meteorology out of terminals and they are consuming water for domestic purposes. Some of the Governmental Buildings have interior plants. These plants are watered once or twice in a week. In period of March 2016 to February 2017, one of them was under construction.

Uncategorised group of water consumers has 8 companies and 7 of which have only restrooms (including toilets, faucets, bidet nozzles). One of them is a take away restaurant and they use water only for cleaning. Most of them are office of construction companies.

Furthermore, there are 3 Petroleum Companies in the airport. These companies provide petroleum to the aircrafts, airport bus services. Water consumption activities are listed in below. These data obtained with water consumption questionnaire for this research. Water consumption activities are listed in below:

- Bidet nozzle
- Cleaning
- Dishwasher
- Faucet
- Interior plants watering
- Landscaping
- Pit cleaner
- Pool cleaning
- Showers
- Toilet
- Washing-up

Catering companies, which are located out of terminals, serve foods to airlines. They produce sandwiches, meats, fish, pasta, salad, pasta, cookies, muffins, desserts, ice cream, fruits, coffees, teas etc. These 3 catering companies have water softening units. Therefore, water softening units have a backwashing. There are restrooms that have showers, bidet nozzles, faucets, urinals and toilets for personnel usage. All of the catering company's ice machines are consuming 2 L water per 1 kg ice-cubes. Before using dishwashers, all of the dishes rinse with pre-rinse spray valves. Trolleys are washing after every flight and it takes 10 – 15 minutes with disinfection and washing. All the disinfection processes in all the catering companies consume 16 L per minutes. These data obtained with water consumption questionnaire for this research. Water consumption activities are listed in below:

- Adding water for foods
- Backwashing
- Clean in place oven
- Cleaning
- Disinfection
- Dishwashers
- Faucets
- General cleaning
- Ice machine
- Pot washing
- Pre-washing
- Showers
- Soft drinks
- Teapot
- Toilet
- Trolley washing
- Urinal
- Vegetable washing
- Washing-up
- Windows cleaning

Airlines and ground services have 8 building in out of terminal area. There are restrooms that in all the buildings. Some of them also have dishwashers. These data obtained with water consumption questionnaire for this research.

Cooling Towers serve all terminals excluding out of terminals areas. They are in operation 9 months in a year and 4 cycles per concentrations. Cooling towers water end-uses are evaporation, drift, windage and splash out, bleed and leaks and overflows. Evaporation is about 85%, bleed is about 13.9%, windage and drifts and leaks and overflows are about 0.3%, windage and splash out is about 0.5%

3.3 Water Consumption Footprinting in Adnan Menderes Airport

Adnan Menderes Airport is located in Tahtalı dam watershed. Therefore, surface and groundwater cannot be used without permission from local water authority-IZSU.

Water is supplied to the facilities from municipal water network (from Tahtali reservoir) and groundwater is provided by private companies. There is also a well in airport area but there is no water consumption from this source.

Surface water transferred all the terminals and out of terminal area. When the water is not enough to meet their demands, transported groundwater is used as additional source. The fire system is fed by ground water.

Transported groundwater is filled into the water storage tanks then transported to end users using 2 lines. One of the line is used for irrigation and fire system and other is sent to water softening units. Transported groundwater is also supplied to the terminals when surface water is inadequate. Ground water is mainly used for cooling towers, irrigation, fire system and to fill the domestic terminals reservoirs.

Annual water consumption rate of the airport was 435,660 m^3 within the research period (March 2016 to February 2017). Considering the consumed water amount annualy and also by taking account to limited water sources within this geographic location, development of water efficiency plan was crucial in terms of environmental and economical aspects.

The overall objective of the study was:

- Water consumption footprinting
- Development of water use efficiency plan

3.3.1 Quantification of Water Consumption in the Airport

Adnan Menderes Airport consumes 435,660 m^3 water annually (as of March 2016 to February 2017) for various purposes. 52% of this amount is provided by ground water resources and rest from municipal water (Figure.3.1).

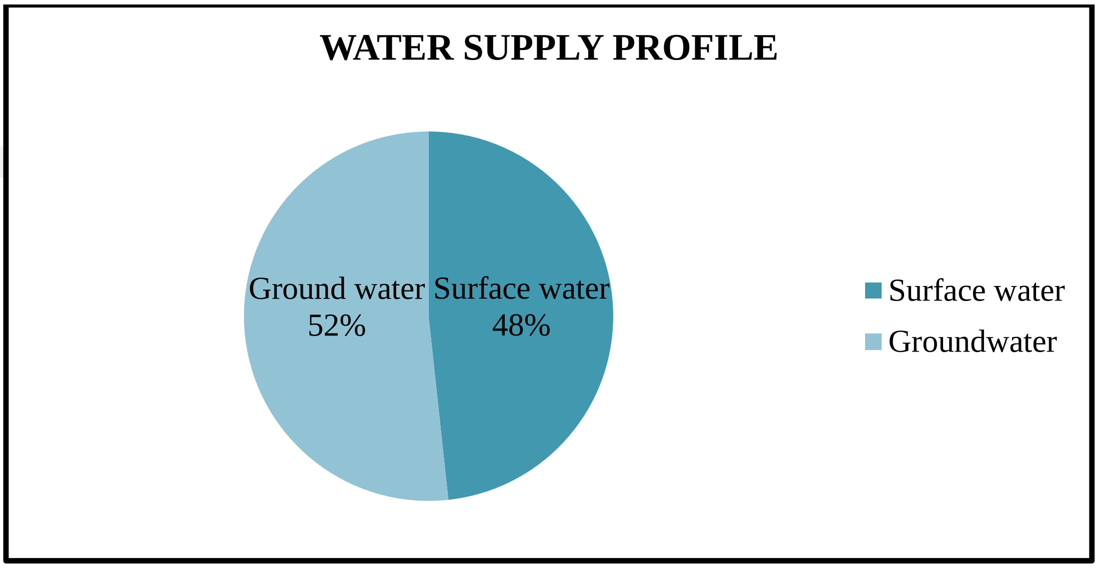

Figure 3.1 Water supply profile of the Adnan Menderes Airport

After water is abstracted from sources it is distributed mainly to:

- Cooling towers
- Terminals (domestic and international)
- Out of terminal buildings
- Irrigation system
- Fire system

There are about 116 water meters installed on the water supply line and distribution network to record water consumtion rates of different end users. Records are available mainly on monthly basis but at some points they could be bi-monthly. In the thesis, water consumption footprinting has been conducted by evaluating records of water meters. Schematic representation of water distribution system and location of water meters are seen in Figure 3.2.

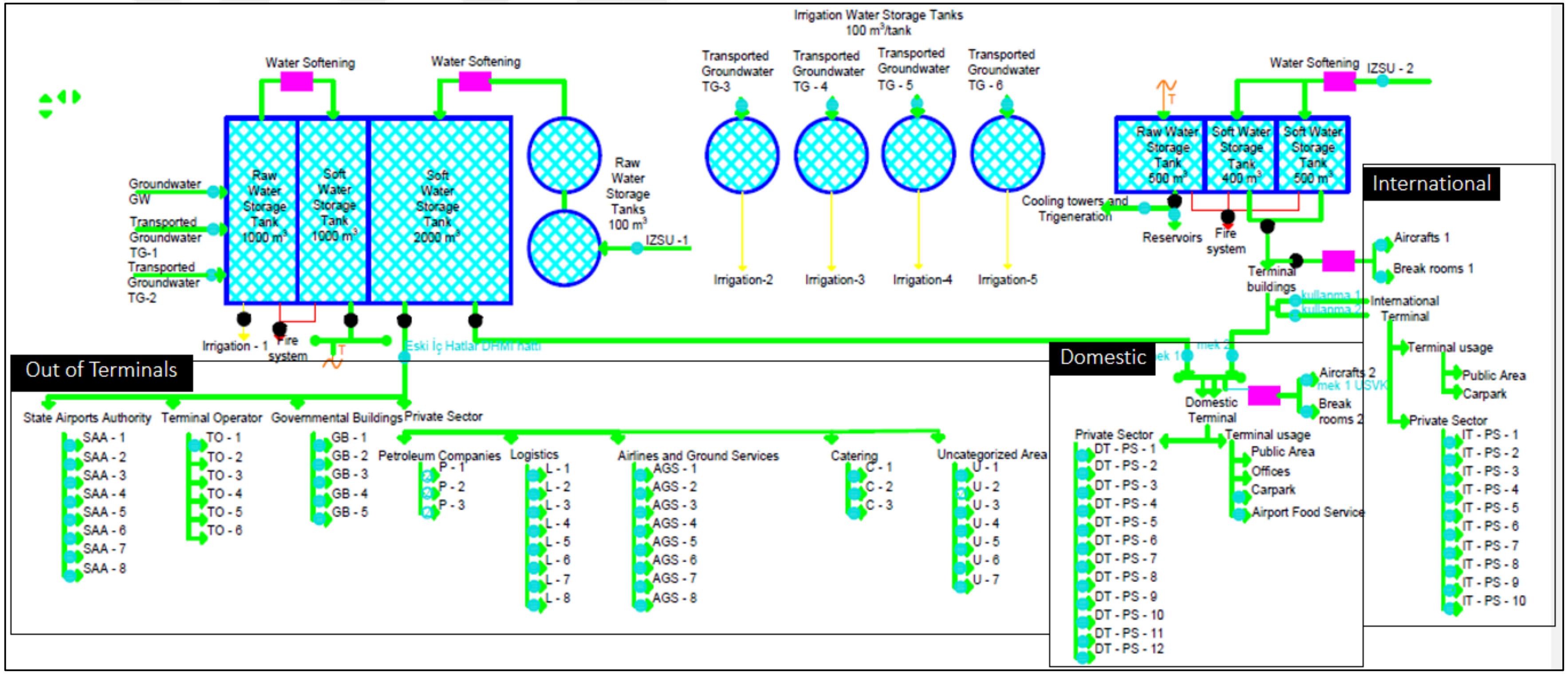

Figure 3.2 Adnan Menderes Airport water distribution system and location of water meters

Amount of water supplied to the system is recorded by 9 water meters. Devices used for ground water supply were nominated as TG (7 devices) and for municipal network as IZSU (2 devices). Location of these devices (on the water supply line) is seen in Fig. 3.2.

There are also devices installed different places along the distribution network measuring water consumption of companies, facilities (WC, car park etc). Number of water meters set for the facilities at distribution network and their annual water consumtion profile is presented in Table 3.2-3.3.

Table 3.2 Number of water meters at water distribution network

Facility	**Number of Water Meters**
Domestic Terminal	32
Cooling Towers	1
Irrigation and Fire	5
International Terminal	24
State Airport Authority Buildings	8
Governmental Buildings	5
Uncategorized Companies Buildings	9
Catering Companies Buildings	3
Airlines and Ground Services Buildings	8
Petroleum Companies Buildings	6
Logistic Buildings	8
Terminal Operator Buildings	1
Reservoir (to WC)	1
Total	111

Table 3.3 Annual water consumption rates of the Adnan Menderes Airport

WATER SUPPLY LINE		WATER DISTRIBUTION LINE		
Water meters (water from supply system)	Water consumption m^3/yr	Water meters (water to end users)	Water consumption m^3/yr	Share %
IZSU1	106,600	DHMI old line	68,258	15.7
İZSU 2	103,770	Mek1	7,005	16
TG 1	63,295	Cooling Towers	112,175	25.7
TG 2	63,728	Reservoir	9,150	2.1
TG 3-4-5-6-7 (directly to irrigation)	98,267	Aircraft 1	372	0.1
		Office breakrooms 1	2,006	0.5
		Use 1	20,530	4.7
		Irrigation	98,267	22.6
		Use 2	4,417	1
		Mek 2	84,813	19.5
		Fire System	28,667	6.6
				100
Total	435660			

As has been mentioned before in the scope of the thesis water distribution system was analysed for 3 terminal seperately to investigate consumption profile of various users and produce preventive measures for them specifically.

- Domestic terminal
- International terminal
- Out of terminal

3.3.2 Domestic terminal water consumption footprinting

Water end use points/activities/equipments at domestic terminal can be summarised as:

- Basket washing
- Bidet nozzle
- Cauldron washing
- Cleaning
- Coffee machine
- Dishwasher
- Faucets
- Hallway cleaning
- Ice machine
- Interior Plant Watering
- Pan washing
- Pavement cleaning
- Pre-rinse spray valves
- Pre-washing
- Showers
- Tea boiler
- Teapot
- Toilet cleaning
- Toilets
- Urinals
- Vegetable washing
- Washing machine

Group of users at the terminal are:

- Public uses (WC + Praying rooms) + Offices (Dishwasher)
- Carpark
- Airport Food Services
- Private sector
- Aircraft
- Office Breakrooms (soft water) - office faucets
- Reservoirs

In the terminal, water (metered by Mek 1 and Mek 2 coded devices) is distributed to private sector (companies), car park, airport food services, offices, aircrafts and public area. Considering the location and water use purposes some of these sub users were evaluated together (e.g public uses and office toilets). It should be noted that "reservoir" line provides water directly to WC's and its metering device is separate (called reservoir). Furthermore water is provided to aircrafts on their request. Therefore there is no permenant consumption for this use.

Monthly water consumption rates for each type of uses in dometic terminal are presented in Table 3.4. Furthermore number of passengers on monthly basis is shown in Figure 3.3.

Table 3.4 Domestic terminal monthly water use by different end-users (m^3)

Domestic terminal Water meter accounting consumption/End user		March	April	May	June	July	August	September	October	November	December	January	February
Mek1 +Mek2	Public area (WC + Praying rooms) + Offices (Dishwasher)	2561	4795	4138	4310	4438	4849	4420	4790	3707	3734	2570	2459
	Carpark-WC	556	707	824	751	668	860	1031	650	622	647	1076	526
	Airport Food Services	604	609	784	748	778	754	1022	670	633	758	696	449
	Private sector (food)	331	296	372	376	447	477	508	437	421	488	547	279
	Private sector (food+accomodation)	3226	806	984	942	609	2507	1218	964	1678	2121	2522	1648
	Aircraft	13	13	14	15	15	15	17	24	14	17	14	9
	Office Breakrooms (soft water) - office faucets	612	669	773	748	743	785	692	662	676	702	618	539
Reservoir	Reservoirs	150	206	300	101	0	0	1317	1946	1297	1387	1296	1150

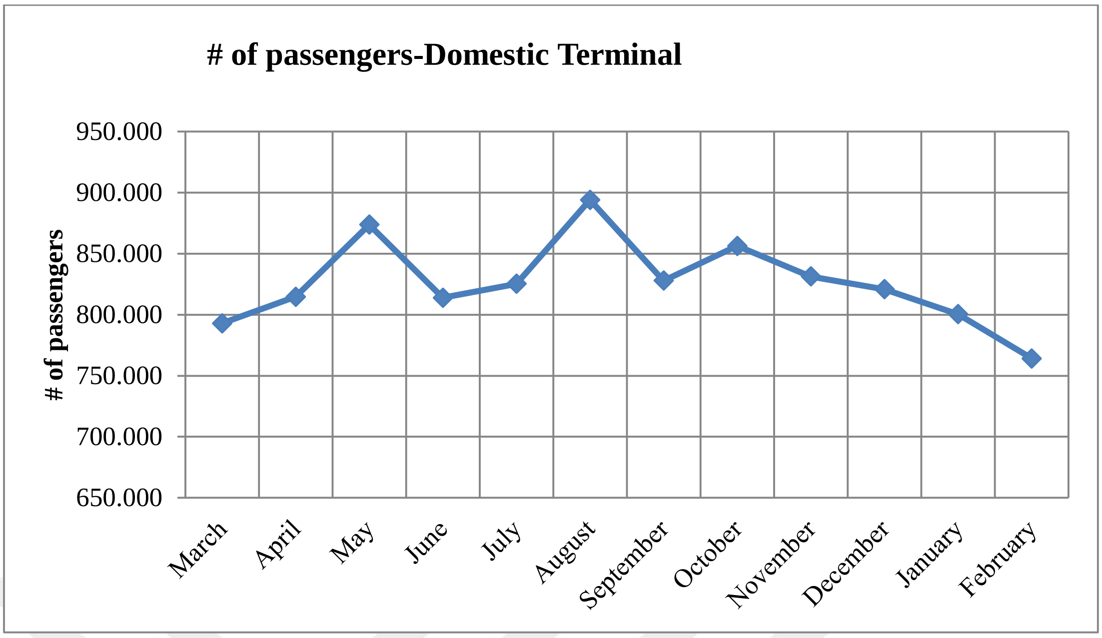

Figure 3.3 Number of passengers-Domestic terminal

Share of water use by end users are depicted in Figure 3.4.

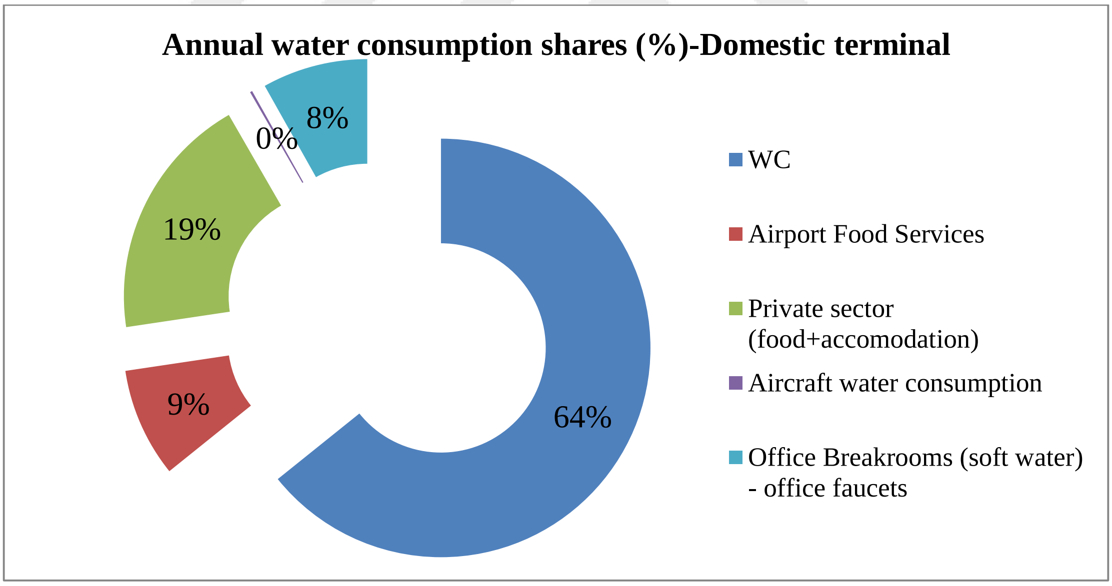

Figure 3.4 Annual water consumption shares of domestic terminal

WC use was the main component of total consumtion by share of 64% in the domestic terminal. Private sector (including food companies and hotel) used 19% of the total.

Monthly fluctuation of water consumption for each use is depicted in Fıgures 3.5 to 3.9.

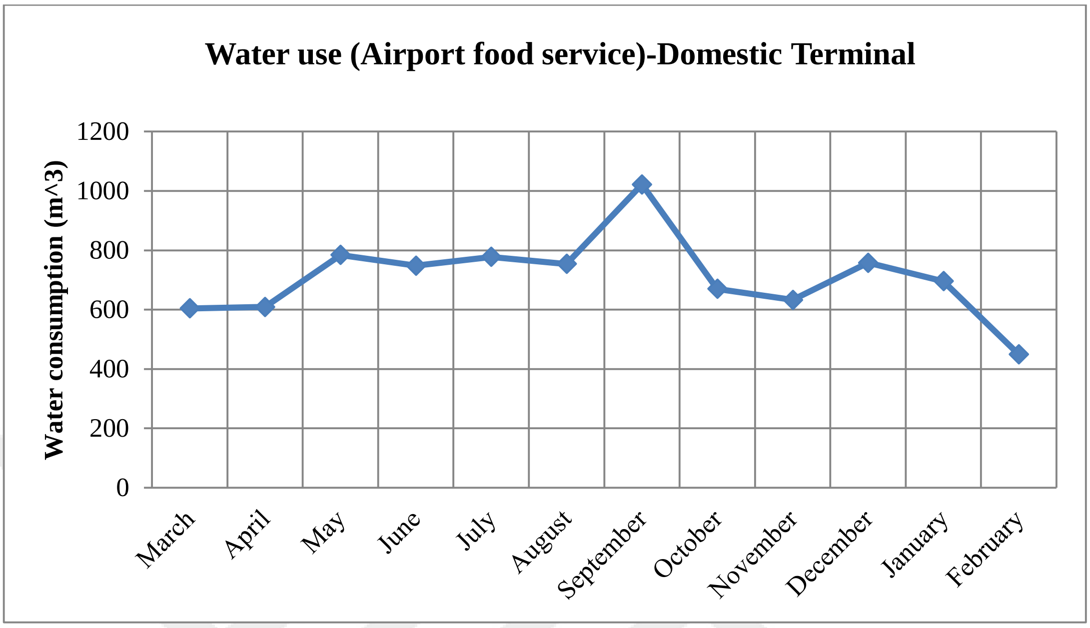

Figure 3.5 Monthly water consumption by Airport food services (domestic terminal)

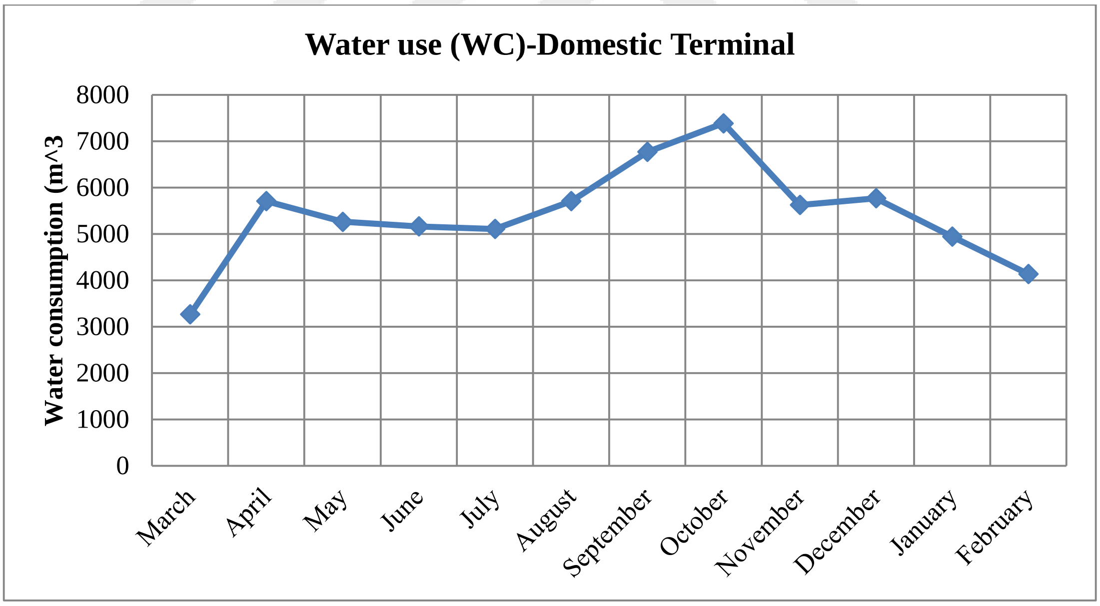

Figure 3.6 Monthly water consumption by WC use (domestic terminal)

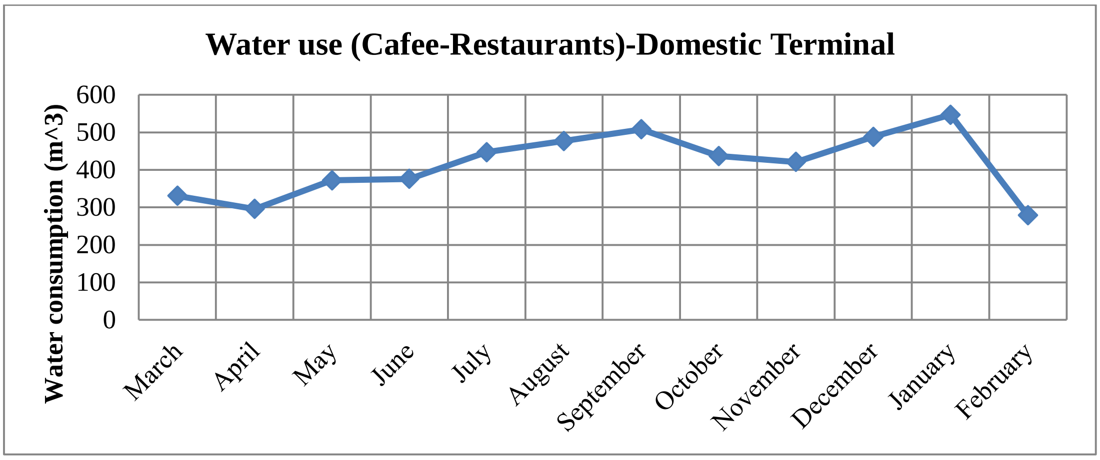

Figure 3.7 Monthly water consumption by private sector-cafee restourants (domestic terminal)

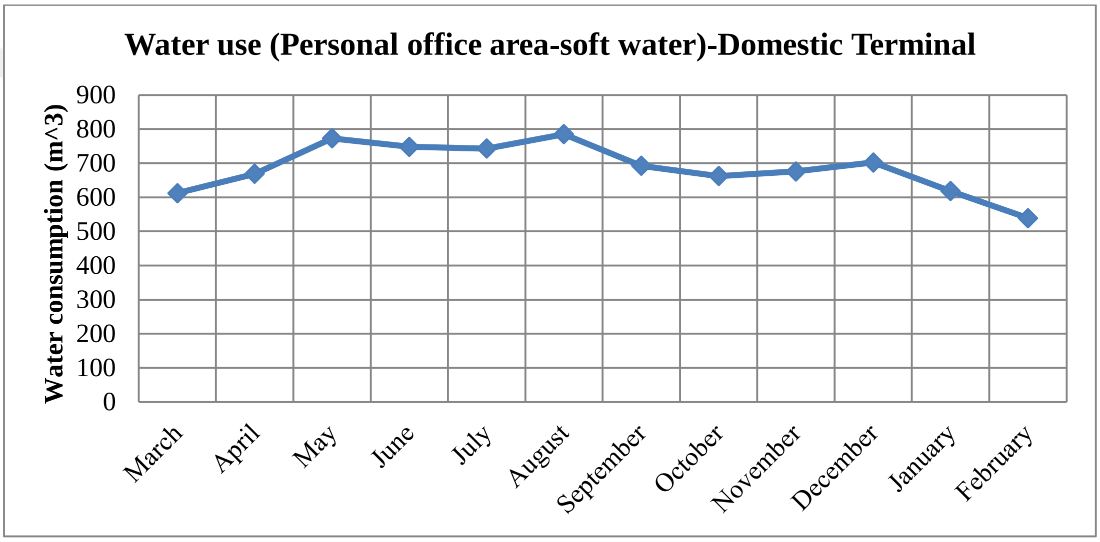

Figure 3.8 Monthly water consumption by offices (domestic terminal)

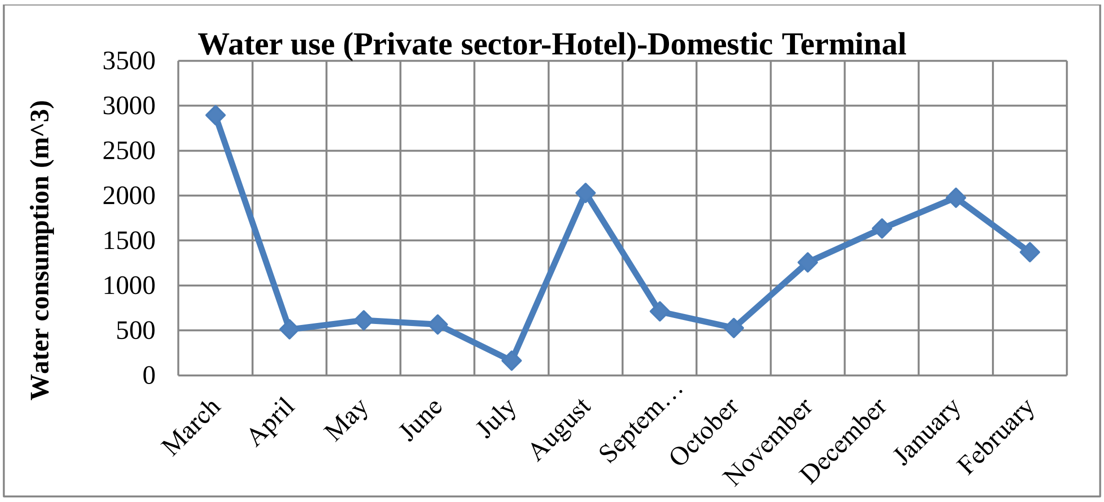

Figure 3.9 Monthly water consumption by hotel (domestic terminal)

As is seen from the figures, water consumption profile showed similar pattern with number of passengers. That means water consumption was increased in summer months, except hotel uses. The reason is that although hotel provided water from domestic terminal, accommodated people was not limited to passengers. People also come from the city.

3.3.3 International terminal water consumption footprinting

Water end use points/activities/equipments at international terminal can be summarised as:

- Bidet nozzle
- Cleaning
- Coffee machine
- Dishwasher
- Faucet
- Ice machine
- Pavement cleaning
- Pre-washing
- Teapot
- Toilet
- Vegetable washing
- Washing-up

Group of users at the terminal are:

- Public uses (WC + praying rooms) + Carpark (WC)
- Private sector
- Aircraft
- Office Breakrooms (soft water) - office faucets

Water metered by “Use 1, Use 2, Aircraft 1 and Breakrooms” devices was distributed to private sector (companies), car park, offices, aircrafts and public area.

Similar to the domestic terminal water was provided to aircrafts on their request. Therefore there was no permenant consumption for this use.

Monthly water consumption rates for each thype of use in international terminal are presented in Table 3.5. Furthermore number of passengers on monthly basis is shown in Figure 3.10. Annual water consumption shares of international terminal is also depicted in Figure 3.11.

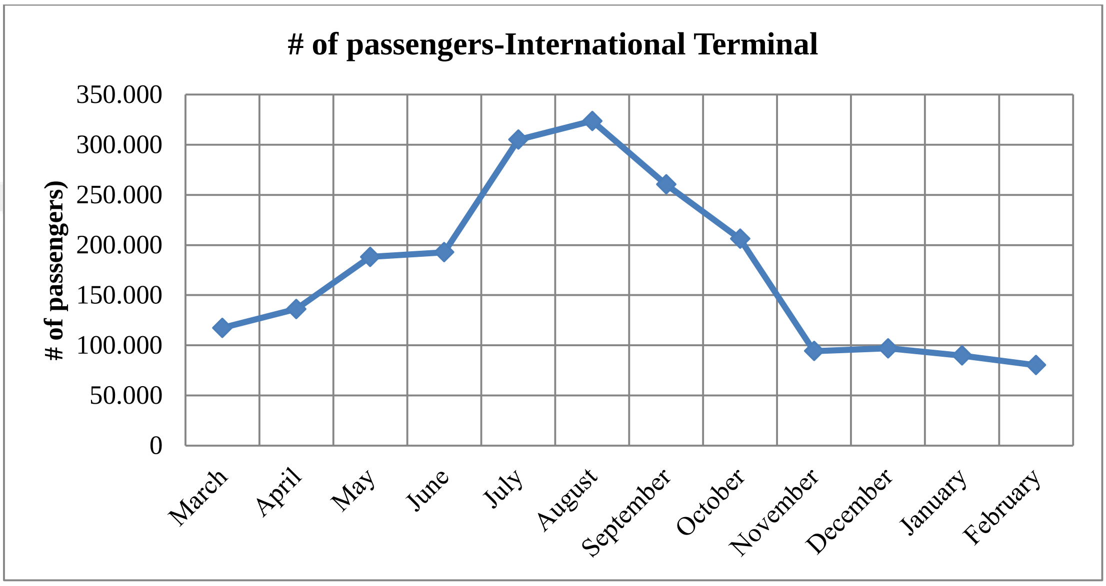

Figure 3.10 Number of passengers-International terminal

Table 3.5 International terminal monthly water use by different end-users (m^3)

International terminal Water meter accounting consumption/End user		March	April	May	June	July	August	September	October	November	December	January	February
Use 1+Use 2+Aircraft+Break rooms	Public area (WC + Praying rooms) + Car park (WC)	2418	2516	2655	2913	3584	3576	1733	917	736	663	652	766
	Private sector	69	63	213	160	206	269	224	115	93	109	240	57
	Aircraft	15	21	32	33	45	44	34	33	18	20	62	15
	Office Breakrooms (soft water) - office faucets	92	149	174	165	201	242	185	167	148	136	243	104

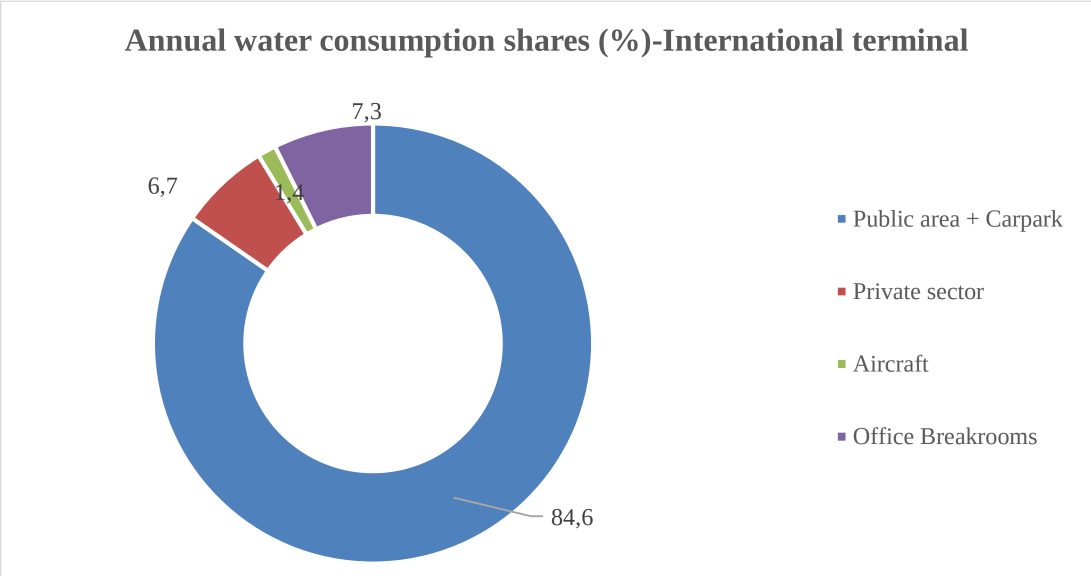

Figure 3.11 Annual water consumption shares of international terminal

WC use was main component of total consumtion by share of 85% in the international terminal. Private sector (including food companies) and offices used 14% of the water in total.

Monthly fluctuation of water consumption for each use is depicted in Fıgures 3.12 to 3.15.

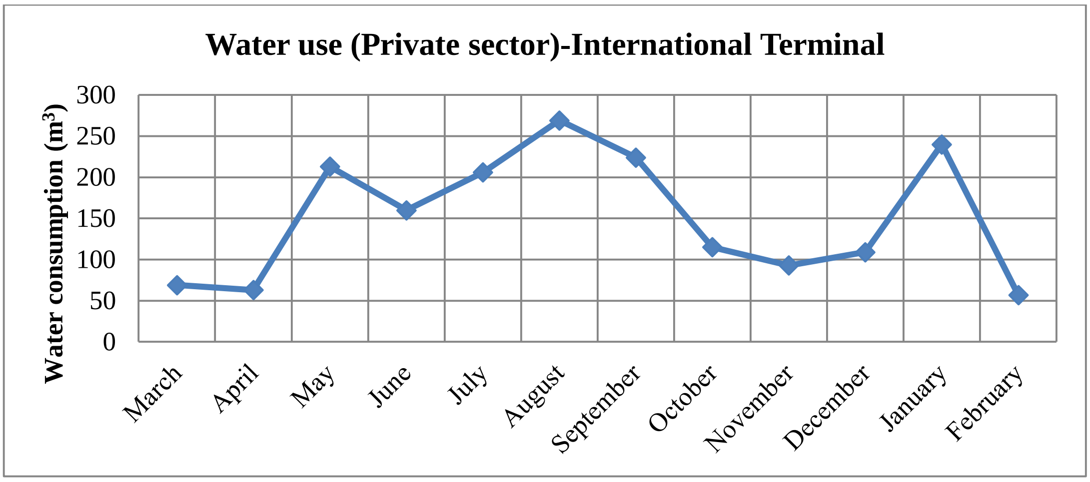

Figure 3.12 Monthly water consumption by private sector (international terminal)

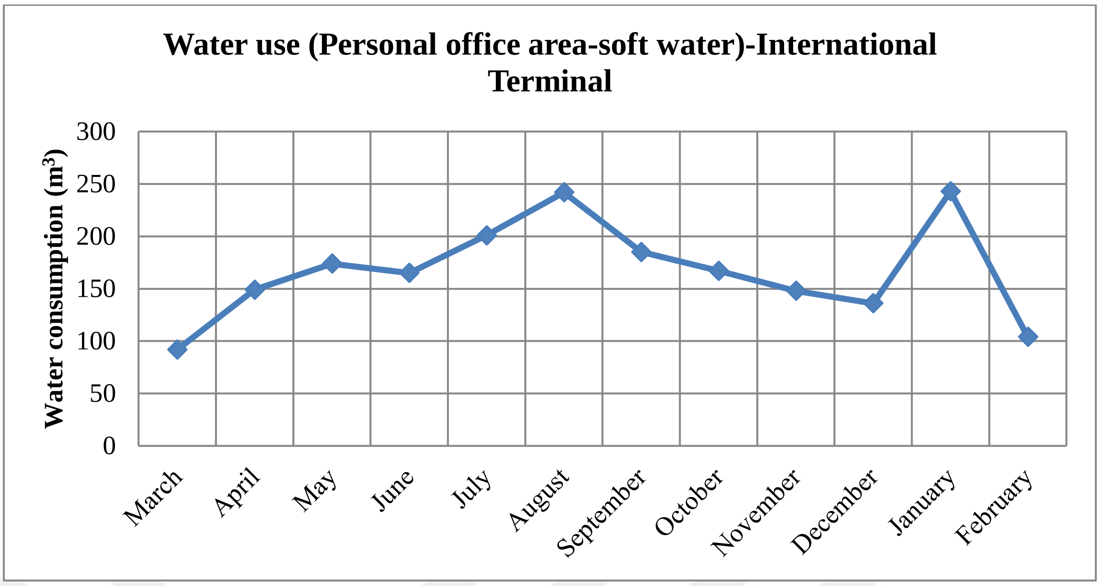

Figure 3.13 Monthly water consumption by offices (international terminal)

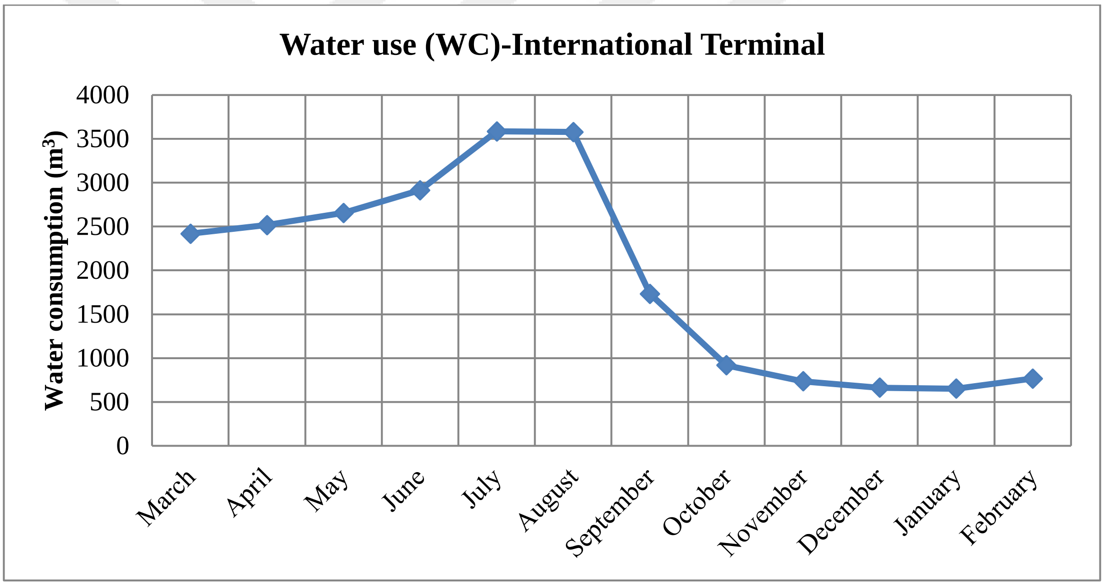

Figure 3.14 Monthly water consumption by passenger use-WC (international terminal)

As is depicted in Figure in 3.12 water consumption rate increased with the increase of number of passengers. In contrast, water amount drastically decreased for WC use after August. The reason was that temporarily international terminal provided water to domestic terminal for WC used (increasing rate in the figure belonged to that period)

In addition to water transfer between terminals (for wc use), food providing companies were also used by domestic and international passenger in both terminals. Therefore water footprinting of WC and food service (L per pax) had to be conducted based on the total water consumption value and also number of passengers in the airport.

3.3.4 Out of terminal facilities water consumption footprinting

Water end use points/activities/equipments at out of terminal facilities can be summarised as:

- Adding water for foods
- Backwashing (Water softening)
- Basin cleaning
- Bidet nozzle
- Clean in Place Oven
- Cleaning
- Disinfection
- Dishwasher
- Faucet
- Kitchen activities
- General cleaning
- Generator cleaning
- Ice machine
- Interior plants watering
- Landscaping
- Mop washing
- Pavement cleaning
- Pit cleaner
- Pool cleaning
- Pot washing
- Praying room
- Pre-washing
- Runaway rubber removal
- Schoerling
- Showers

- Snow removal
- Soft drinks
- Street sweeper
- Teapot
- Toilet
- Trolley washing
- Urinal
- Vegetable washing
- Washing-up
- Weir cleaning
- Window cleaning

Group of users at this site are:

- Public sector
  - ✓ State Airport Authority
  - ✓ Terminal Operator
- Governmental Buildings
  - ✓ Private Sector
  - ✓ Petroleum Companies
  - ✓ Logistics
  - ✓ Airlines and Ground Services
  - ✓ Catering companies
  - ✓ Uncategorised users

Since frequency of the records of the water meters showed difference in this area this group was evaluated by examining annual coonsumptions. Data was presented in Table 3.6.

Table 3.6 Out of terminal facilities annual water consumption

Water user	**Annual consumption (m^3/yr)**	**Share in total use (%)**
Public sector		
State Airport Authority	25,651	37.8
Terminal Operator	785	1.2
Governmental Buildings	9,613	14.2
Private Sector		
Petroleum Companies	980	1.4
Logistics	4,569	6.7
Airlines and Ground Services	9,895	14.6
Catering	13,879	20.4
Uncategorised Area	2,552	3.7
Total		100

State airport authority, catering companies, airline groung services and governmental buildings were the main users out side of the terminal in total.

3.3.5 Passenger based water consumption of the terminals

As has been mentioned before, there was water transfer between terminals (for wc use) and use of food providing sectors by domestic and international passenger in both terminals. Therefore water footprinting of WC and food service uses has been made based on the total water consumption value and also number of passengers in the airport.

Number of passenger versus water consumption rates (WC use and water consumption of food services in total) was plotted (see figure 3.15) and the graphic showed that there was a linear correlation between these variables (R^2=0.85).

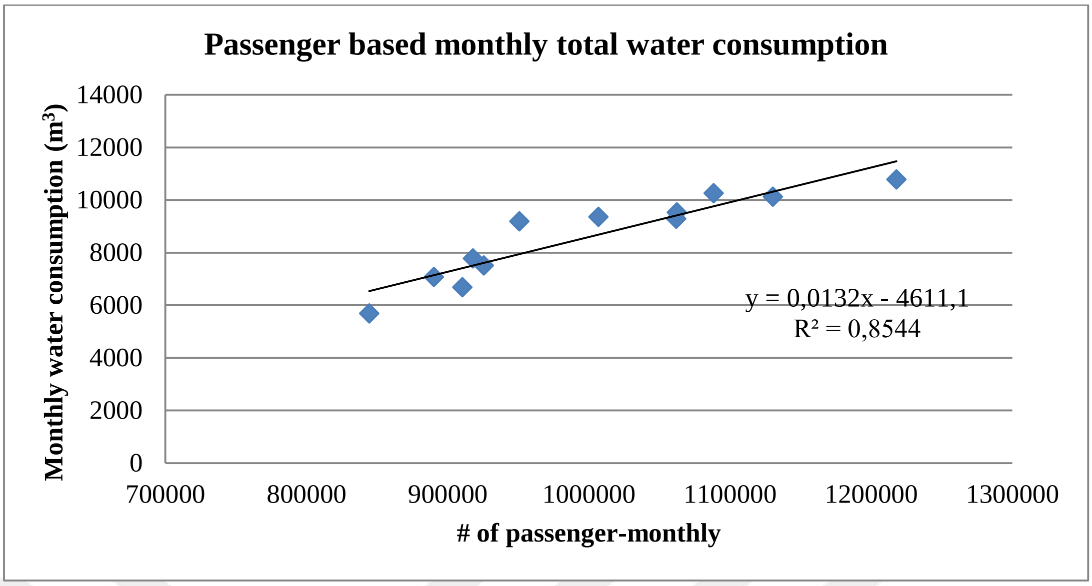

Figure 3.15 Relationship between number of passengers and water consumption values (WC+Food consumption)

Monthly change of L per pax (liter per pessanger) values for WC use and food consumption together are shown in Figure 3.16.

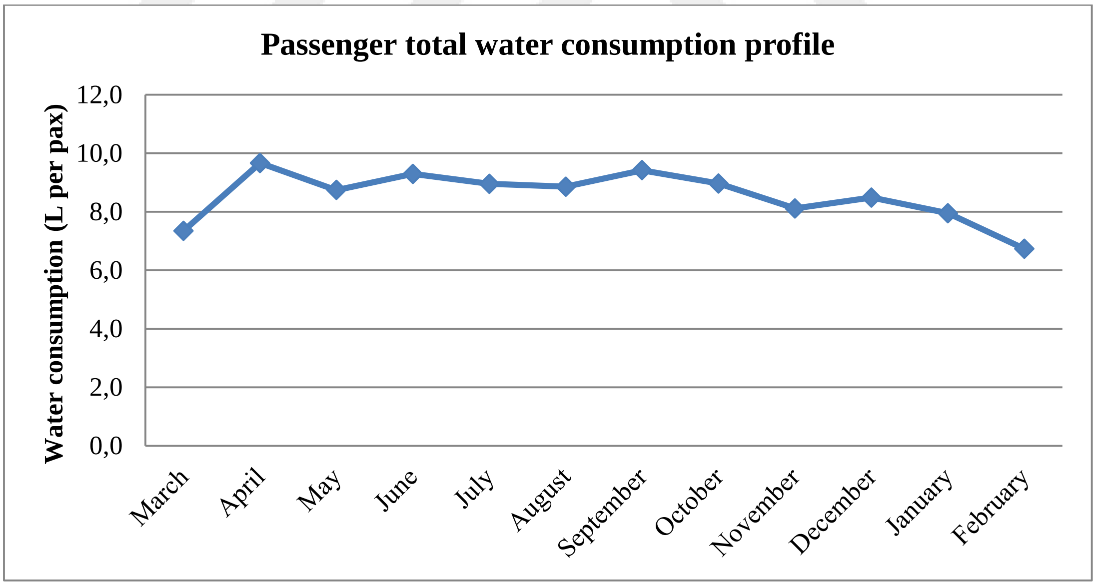

Figure 3.16 Monthly change of L per pax values

While water used for WC changed between about 6-8.5 L per pax, this value was between 1-1.5 L per pax for food consumption. Therefore passenger based uses was fluctuated between 6.5-10 L per pax in the airport (see Figure 3.17).

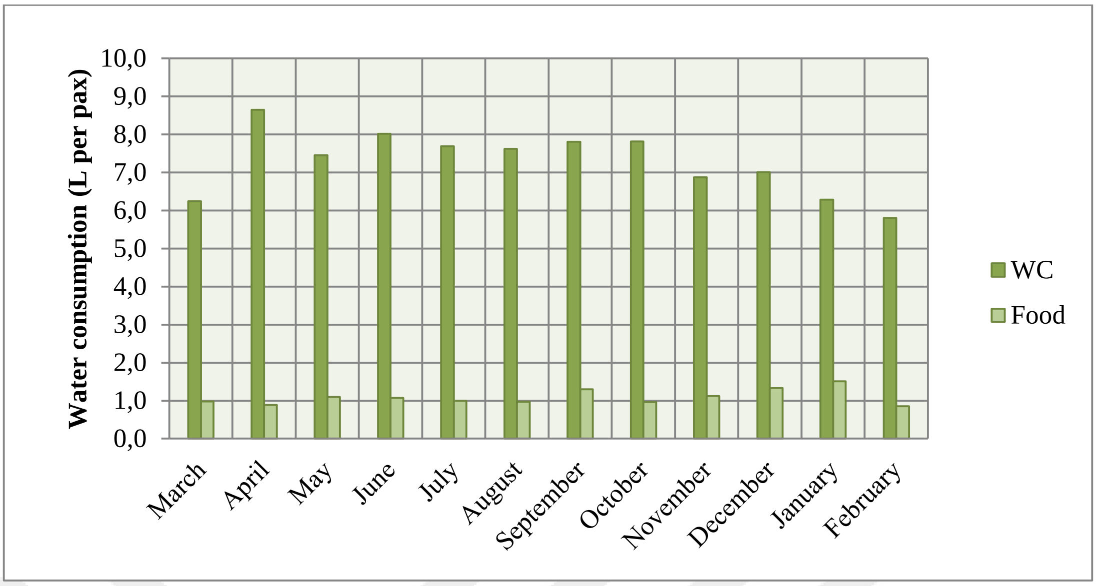

Figure 3.17 Litter per pax values for WC use and food consumption

Monthly change profile for WC use and food consumption was quite similar to change of number of passengers (see Figure 3.18-3.19)

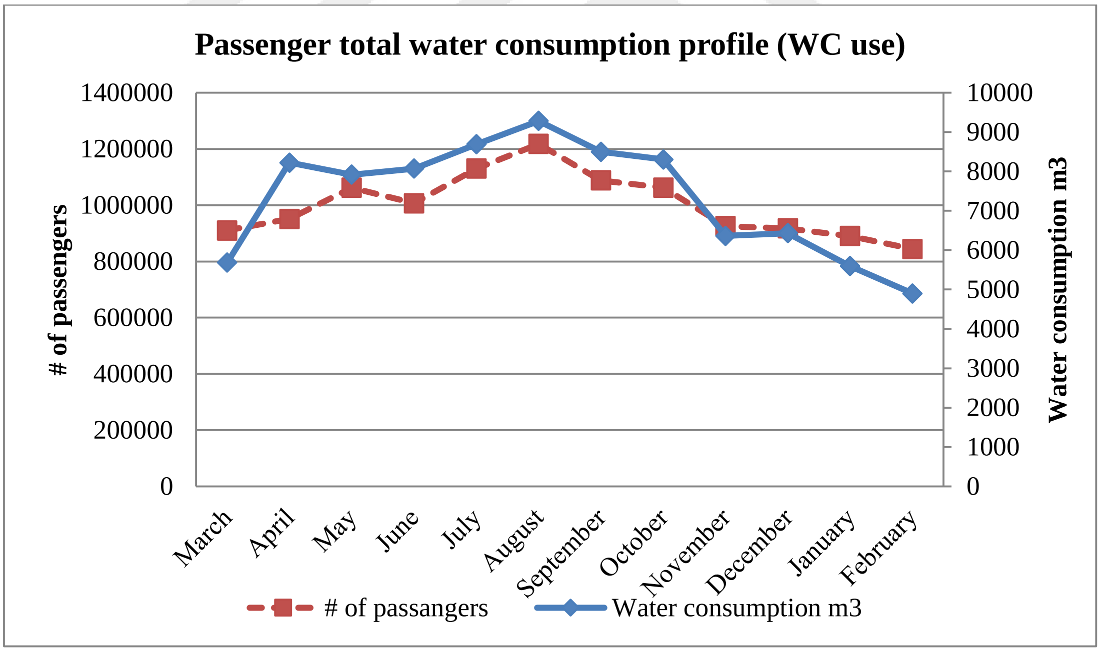

Figure 3.18 Passenger & total water consumption profile (WC use)

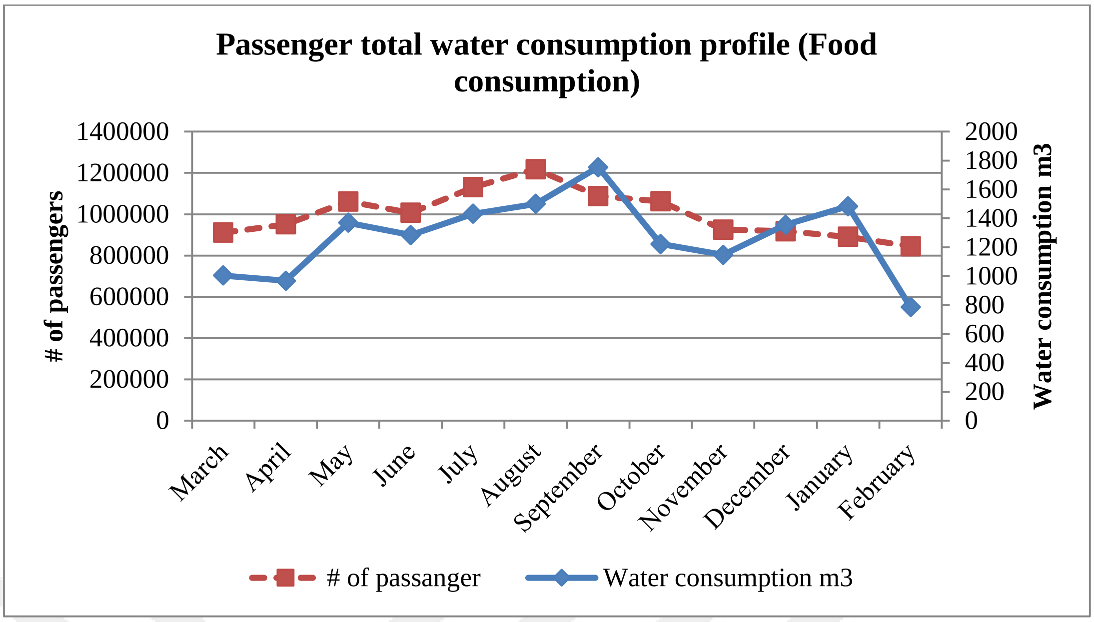

Figure 3.19 Passenger & total water consumption profile (Food consumption)

3.4 Water Efficiency Plan for Adnan Menderes Airport

Within the airport, there were number of particularly high users/activities which were presented in Table 3.7.

Table 3.7 High water users/activities in the airport

Water users/activities	**Annual consumption (m^3/yr)**	**Share in total consumption (%)**
Irrigation	98,267	23
Fire system	28,667	7
Cooling towers	112,175	26
Terminal WC use	87,968	20

Irrigation, cooling towers and wc use comprised about 70% of the total use. Therefore priority should be given minimization of the consumption for these activities. These measures and their applicability in terms of economical and physical factors are presented in Table 3.8.

Table 3.8 Water minimization solutions

Water users/activities	**Water efficiency solutions**	**Economical applicability**	**Physical applicability**
Irrigation	Use of artificial grass	1*	5
	Automatic irrigation systems installation (Available)	3	5
	Rainwater harvesting for irrigation	3	2
	Use of sub-surface irrigation (Available)	3	3
Fire system (Pressure testing of the fire fighting system is carried out regularly and requires potable water. At present fire testing water is discharged to stormwater system and not re-purposed.)	Collection of fire testing water for re-use or re-purposing for non-potable use is proposed. (Available)	3	3
Cooling towers (Cooling towers also use high volume water. Current system recirculates water for a set number of times and must then dispose of the water)	Changing chillers	1	1
	Optimising cooling tower makeup water consumption, convert open loop evaporative humidifiers with closed loop versions, replace open loop water cooled condensers by air cooled, or closed-loop water cooled condensers	1	1

Table 3.8 continues

Water users/activities	**Water efficiency solutions**	**Economical applicability**	**Physical applicability**
Terminal WC use	Increasing rainwater and greywater capacity	3	1
	Replacing restroom fixtures with high-efficiency ones	2	5
General comments	Use grey water for landscaping; capture and collect rain water for non-potable uses	1	1
	Training and education of airport staff;	5	3
	Improved water consumption monitoring	3	3

* 1:very low 2:low 3:medium 4: high 5: very high

CHAPTER FOUR
RESULTS

During the research period (from March 2016 to February 2017) the Adnan Menderes Airport served to about 12 million passengers and 81 thousand aircrafts. These passengers and aircrafts were served by various services by airport authorities. These services were linked by water consumption directly or indirectly. Annual water consumption was about 436,000 m^3/year in total.

Within the Airport, there were a number of particularly high users/activities:

- Irrigation (23% of the total use)
- Fire control system (7% of the total use)
- Cooling towers (26% of the total use)
- Terminal WC use (20% of the total use)

While water used for WC changed between about 6-8.5 L per pax, this value was between 1-1.5 L per pax for food consumption. Therefore passenger based uses was fluctuated between 6.5-10 L per pax in the airport. This value was below world average rates.

Based on this analysis, the airport authority should consider following projects in near future:

- Use of artificial grass
- Rainwater harvesting for irrigation
- Replacing restroom fixtures with high-efficiency fixtures
- Increasing rainwater and greywater capacity (for WC use)
- Revising the operations of cooling towers
- Use gray water for landscaping; capture and collect rain water for non-potable uses
- Training and education of airport staff

- Improved water consumption monitoring

Economical and physical applicability of these methods were also assessed based on judgement of airport technical staff. It was concluded that the most economical measure was “training and education of airport staff” to minimise water consumption. Furthermore physical applicability of “replacing restroom fixtures with high-efficiency ones and use of artificial grass” were relatively higher than the other proposed methods.

CHAPTER FIVE
CONCLUSION

Airports are potential environments for implementing programs aiming conserving water due their large consumption, generally for non-potable purposes such as water cooling systems, fire control, cleaning and washing of vehicles, runways and aircrafts and also public uses. The study focused on water consumption footprinting and development of water efficiency plan for Adnan Menderes airport, in Turkey. Research period covered 12 months and consumption data obtained from 116 water meters were analysed for water footprinting. Annual water consumption was about 436,000 m3/year in total. Results of the footprinting study showed that cooling towers, irrigation, terminal WC uses and fire control system accounted high use rated with 26%, 23%, 20% and 7 %. While water used for WC changed between about 6-8.5 litter per pax, this value was between 1-1.5 litter per pax for food consumption. Based on these results water efficiency plan was developed. In this plan several methods were suggested to minimize water consumption. Among them “training and education of airport staff” was proposed as the most economical solution. Furthermore “improved water consumption monitoring” system could be suggested as applicable method considering economical and physical aspects and should gain priority. Then alternative measures could be chosen based on their economical and physical applicability.

APPENDICES

APPENDIX 1

ABBREVATION

ACI	Airport Council International
ADR	Aeroporti di Roma
AENA	Adolfo Suárez Madrid-Barajas Airport
AIRAH	Australian Institute of Refrigeration Air Conditioning and Heating Inc.
AKL	Auckland International Airport
ATAG	Air Transport Action Group
ATL	Hartsfield-Jackson Atlanta International Airport
BAA	Baltic Aviation Academy
BRS	Bristol Airport
BRU	Brussels Airport
CAA	Civil Aviation Authority
CANSO	Civil Air Navigation Services Organisation
CBR	Canberra Airport
DHMI	General Directorate of State Airports Authority in Turkey
EWS	European Water Stewardship
FAA	Federal Aviation Administration
FAO	Food and Agriculture Organization of the United Nations
GAL	Gatwick Airport
GLA	Glasgow Airport
GRI	Global Reporting Initiative
HKIA	Hong Kong International Airport
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICCAIA	International Coordinating Council of Aerospace Industries Association
IFC	International Finance Corporation

ITM	Osaka International Airport
IRICEN	Indian Railways Institute of Civil Engineering
LHR	Heathrow Airport
MAD	Madrid Barajas Airport
MLA	Malta International Airport
MUC	Munich Airport
NCDENR	North Carolina Department of Environment and Natural Resources
NFTA	Niagara Frontier Transportation Authority
NGO	Non-governmental Organization
NRDC	Natural Resource Defence Council
NYSDEC	New York State Department of Environmental Conservation
SAA	State Airport Authority
SFO	San Francisco International Airport
SFWMD	South Florida Water Management District
SWF	Steward International Airport
SYD	Sydney Airport
TO	Terminal Operator
UNEP	United Nation Environmental Protection
VIE	Vienna International Airport
WHO	World Health Organization
WMP	Water Management Plan
WRF	Water Research Foundation
YVR	Vancouver International Airport

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