Management of wastewater in rural districts of Istanbul metropolitan municipality

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ABSTRACT

Decentralized systems play a big role in wastewater treatment in rural areas. The aims of this study are to address the wastewater treatment and disposal problems for rural districts of Istanbul, to discuss the efficiencies of currently operated systems and to offer new appropriate wastewater treatment systems for small communities having a population up to 5,000. The management and final disposal alternatives for sludge generated in septic tanks are also discussed within the scope of this study. A sequencing batch reactor (SBR) system serving 2,500 people and a hybrid constructed wetland system serving 500 people are presented as case studies. A thorough evaluation based on the capacity and performance of the existing wastewater treatment systems in rural districts revealed that a number of these systems are not operating at their optimum. Improperly constructed sewer lines receive a lot of infiltration and inflow (I & I) after rainfall events, decreasing treatment performance and causing operational difficulties. Natural treatment systems such as constructed wetlands prove a viable alternative in these communities, especially for villages with populations less than 500 people.

Key words | constructed wetlands, infiltration, rural districts, SBR systems, wastewater management

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INTRODUCTION

Istanbul is the most important industrial and commercial center of Turkey, with a current population around 15 million. The annual population growth rate of Istanbul (~2.1%), as the average for the last 5 years, is approximately 1.5 times the overall population growth rate of Turkey (~1.4%) (Ozturk & Altay 2015). Municipal infrastructure of wastewater in Istanbul is not as well developed as its water supply system. A sanitary sewer system serving 98% of the population with a length of ~14,000 km exists in Istanbul (ISKI 2017). A part of the existing sewer system is a combined system, and mainly bears significant amounts of stormwater. The wettest months in Istanbul are January and December, while the driest months are June and July. The sewer system overflows from time to time during intense precipitation, resulting in surface water pollution at a local level with health risks for the community.

Decentralized systems play a big role in wastewater treatment in small communities (Engin & Demir 2006; Libralato *et al.* 2012). In Istanbul, wastewaters from rural populations of between 500 and 5,000 inhabitants are treated using individual septic systems, packaged biological treatment systems, low-cost stabilization ponds on-site, conventional activated sludge systems, or in some cases with advanced biological treatment systems that remove nutrients (Ozturk & Altay 2015). There are currently 66 small wastewater treatment plants (WWTPs) with capacities ranging from 125 to 1,730 m^3/day in rural districts of Istanbul. Of these, 41 are located in the European side of the city and 25 are located in the Asian side (Figure 1, Table 1).

As can be seen from Table 1, existing small wastewater treatment plants are predominantly designed as conventional activated sludge systems. There is only one natural treatment system designed as a hybrid constructed wetland system. 33 of the small WWTPs are located in drinking water basins. These need to be upgraded to advanced biological treatment for efficient removal of nutrients and emerging organic contaminants.

The aims of this study are to address the wastewater treatment and disposal problems for rural districts of Istanbul, to discuss the efficiencies of currently operated

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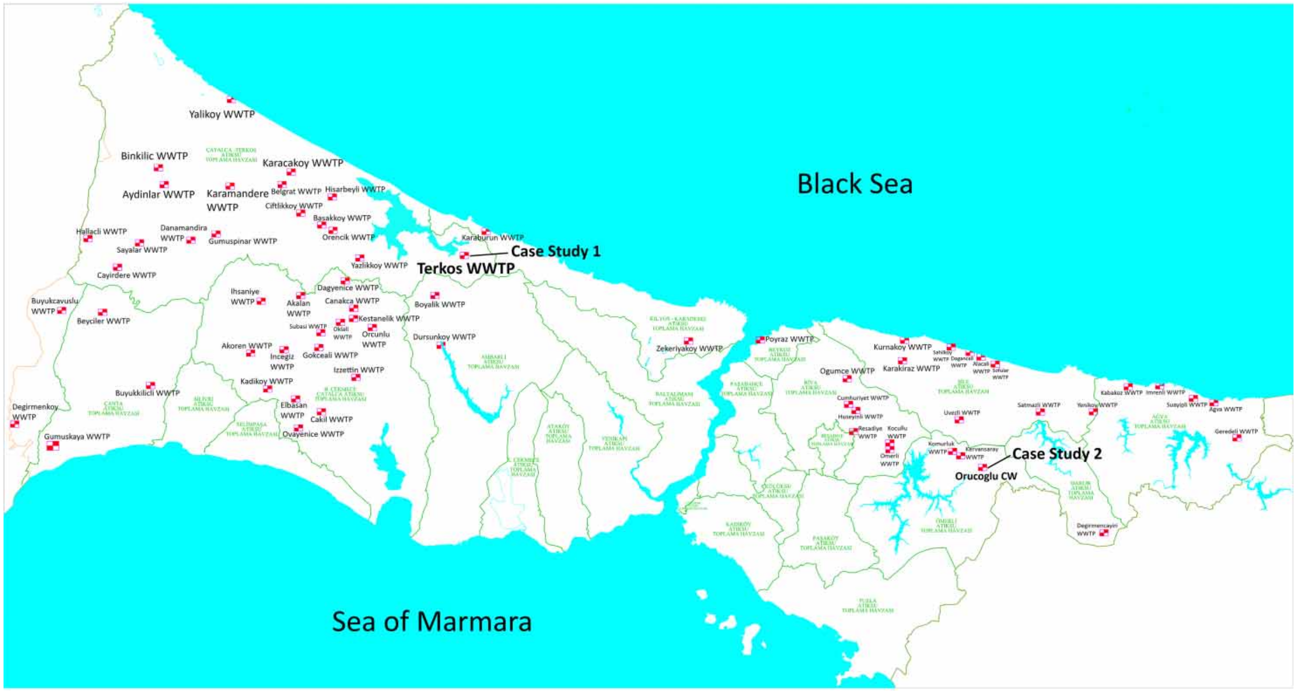

Figure 1 | Locations of small wastewater treatment plants in rural districts of Istanbul.

systems and to offer new appropriate wastewater treatment systems for small communities having a population of up to 5,000. A sequencing batch reactor (SBR) system serving 2,500 people and a hybrid constructed wetland system serving 500 people are presented as case studies within the scope of this paper.

CASE STUDY AREAS

Terkos Advanced Biological Wastewater Treatment Plant (WWTP) and Orucoglu Constructed Wetland (CW) are selected to be presented as case studies in this paper. Terkos Advanced Biological WWTP is located in the northern part of the European side of Istanbul near Terkos Lake (Figure 1). It has a capacity of 1,730 m^3/day and has been designed as two parallel sequencing batch reactors (SBR), which is a fill-and draw activated sludge system for wastewater treatment.

Orucoglu CW is located on the Asian side of Istanbul near Omerli Reservoir (Figure 1). Orucoglu CW system consists of two parallel horizontal subsurface flow wetlands (HSFWs) with a total surface area of 500 m^2, and three vertical subsurface flow wetlands (VFWs) with a total

Table 1 | List of small wastewater treatment plants (WWTPs) in Istanbul

		Name	Year started	Capacity (m^3/d)
European side	1	Terkos advanced SBR WWTP	2000	1,730
	2	Akalan package WWTP	2008	400
	3	Belgrat package WWTP	2008	50
	4	Kestanelik conventional WWTP	2010	500
	5	Örcünlü conventional WWTP	2010	250
	6	Yazlik conventional WWTP	2012	250
	7	Subasi conventional WWTP	2012	250
	8	Canakca conventional WWTP	2010	500
	9	İzzettin conventional WWTP	2010	500
	10	Oklali conventional WWTP	2011	500

(*continued*)

Table 1 | continued

		Name	Year started	Capacity (m^3/d)
	11	Boyalik conventional WWTP	2011	250
	12	Ihsaniye conventional WWTP	2011	500
	13	Basakkoy conventional WWTP	2010	250
	14	Beyciler conventional WWTP	2013	1,000
	15	Binkilic conventional WWTP	2014	1,000
	16	Ciftlik conventional WWTP	2014	1,000
	17	Karaburun conventional WWTP	2014	2,000
	18	Karaca conventional WWTP	2014	1,000
	19	Yali conventional WWTP	2014	1,000
	20	Degirmenkoy conventional WWTP	2014	2,000
	21	Sayalar conventional WWTP	2014	500
	22	Cayirdere conventional WWTP	2014	500
	23	Hallacli conventional WWTP	2014	500
	24	Danamandira conventional WWTP	2014	500
	25	Aydinlar conventional WWTP	2014	500
	26	Gumuspinar conventional WWTP	2014	500
	27	Karamandere conventional WWTP	2014	500
	28	Zekeriyakoy conventional WWTP	2016	4,000
	29	Cakil conventional WWTP	2016	1,000
	30	Incegiz conventional WWTP	2016	1,000
	31	Dursunkoy conventional WWTP	2016	500
	32	Dagyenice conventional WWTP	2016	500
	33	Hisarbeyli conventional WWTP	2016	500
	34	Orencik conventional WWTP	2016	500
	35	Gokceali conventional WWTP	2016	500
	36	Elbasan conventional WWTP	2016	500
	37	Ovayenice conventional WWTP	2016	500
	38	Akoren conventional WWTP	2016	500
	39	Buyukkilicli package WWTP	in progress	400
	40	Buyukcavuslu package WWTP	in progress	1,000
	41	Silivri Kadikoy package WWTP	in progress	800
Asian side	42	Geredeli Village conventional WWTP	2013	250
	43	Kabakoz Village conventional WWTP	2013	250
	44	Sofular Village conventional WWTP	2013	250
	45	Alacali Village conventional WWTP	2013	250
	46	Dogancali Village conventional WWTP	2013	500
	47	Kurnakoy Village conventional WWTP	2013	250
	48	Cumhuriyet Village conventional WWTP	2013	500
	49	Uvezli Village conventional WWTP	2013	250
	50	Satmazli Village conventional WWTP	2013	500
	51	Suayipli Village conventional WWTP	2013	250
	52	Degirmencayiri Village conventional WWTP	2013	250
	53	Omerli conventional WWTP	2008	500
	54	Agva advanced membrane WWTP	2010	4,000
	55	Komurluk conventional WWTP	2008	125
	56	Sahilkoy conventional WWTP	2011	250
	57	Imrenli conventional WWTP	2012	250
	58	Karakiraz conventional WWTP	2012	250
	59	Kocullu conventional WWTP	2012	250
	60	Kervansaray conventional WWTP	2012	250
	61	Yenikoy conventional WWTP	2008	200
	62	Ogumce conventional WWTP	2010	200
	63	Orucoglu constructed Wetland	2009	125
	64	Huseyinli Village conventional WWTP	2013	2,000
	65	Resadiye Village conventional WWTP	2013	2,000
	66	Poyraz conventional WWTP	2017	250

Table 2 | Average monthly performance data for the Terkos Advanced WWTP in 2017

	COD (mg/L)		BOD_5 (mg/L)		TN (mg/L)		TP (mg/L)		TSS (mg/L)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
January	35	19	16	3	12.7	9.2	0.4	0.1	43	14
February	88	23	37	7	18.3	11.8	1.1	0.4	137	9
March	77	27	40	5	17.0	7.9	1.0	0.2	42	12
April	59	20	30	8	14.0	7.0	1.9	1.0	60	9
May	116	38	62	9	14.5	10.6	2.0	1.0	63	13
June	173	33	75	11	12.6	6.8	1.5	0.4	133	7
July	123	44	72	24	16.4	6.9	2.1	0.8	120	18
August	124	50	62	21	13.4	8.2	2.0	0.6	69	15
September	194	77	102	15	17.3	7.5	2.5	1.5	134	49
October	116	28	76	8	16.4	5.1	2.2	1.5	43	17
November	90	22	51	4	14.7	5.2	1.6	0.4	58	6
December	102	17	45	5	12.3	4.2	1.3	0.5	81	11

surface area of 250 m^2. The system has been operated without effluent circulation with an option to activate effluent circulation when necessary (Ayaz *et al.* 2008).

METHODS

Monthly or weekly samples were collected from the small wastewater treatment plants operated by Istanbul Water and Sewerage Administration (ISKI). Influent and effluent parameters were measured in ISKI laboratories according to *Standard Methods* (APHA 2012). Statistical analyses were done using version 25 of the IBM SPSS software Package (IBM, Armonk, New York, USA).

RESULTS AND DISCUSSION

Average monthly performance data for the Terkos WWTP are given in Table 2. Average removal efficiencies for chemical oxygen demand (COD), biochemical oxygen demand (BOD_5) and total suspended solids (TSS) were 68%, 81% and 80%, respectively. As for the nutrients, 49% total nitrogen (TN) removal and 61% total phosphorus (TP) removal was achieved.

As can be seen from Table 2, the influent water is classified as low strength most of the time, especially when there is rainfall. The reason for this is improperly constructed sewer lines which receive a lot of inflow and inputs from groundwater after rainfall events. In Terkos basin, stormwater and wastewater are collected separately and sewer pipes are laid at a depth range of 2.8 to 4.5 m below ground level, while the local groundwater table around the serviced area is between 3 and 9 m below ground level (ISKI, unpublished). This makes the sewer pipes prone to groundwater seepage. The combined plot of maximum daily flow in each month and the Cumulative Deviation from Mean (CDFM) of monthly rainfall between 2015 and 2017 indicates that the maximum flow is responding to the rainfall pattern (Figure 2). Hence, the design capacity of 1,730 m^3/day is exceeded most of the time during rainfall events. Similar problems exist in several of the WWTPs listed previously.

Inflow and Infiltration, commonly referred as 'I&I', is a frequently seen problem in wastewater treatment systems around the world (Weiss *et al.* 2002; Staufer *et al.* 2012; Pawlowski *et al.* 2014). Inflow is defined as the clean water entering sewer pipes at direct points such as manhole covers and roof drains connected to sewer pipes. Infiltration, on the other hand, refers to the water that enters sewer pipes mostly from groundwater seeping through pipe joints or faulty locations along the pipe (EPA 2014). As a result, operational difficulties arise, treatment performance decreases and cost of operation increases due to higher energy demand and use of chemicals (Karpf & Krebs 2011). If necessary actions to mitigate this problem are not taken, the impacts are expected to become more severe as the infrastructure ages and deteriorates. To tackle this problem, ISKI is planning to rehabilitate existing sewer lines with proper internal sealing. Beside sewer pipes, manholes can also be structurally rehabilitated. There have been successful

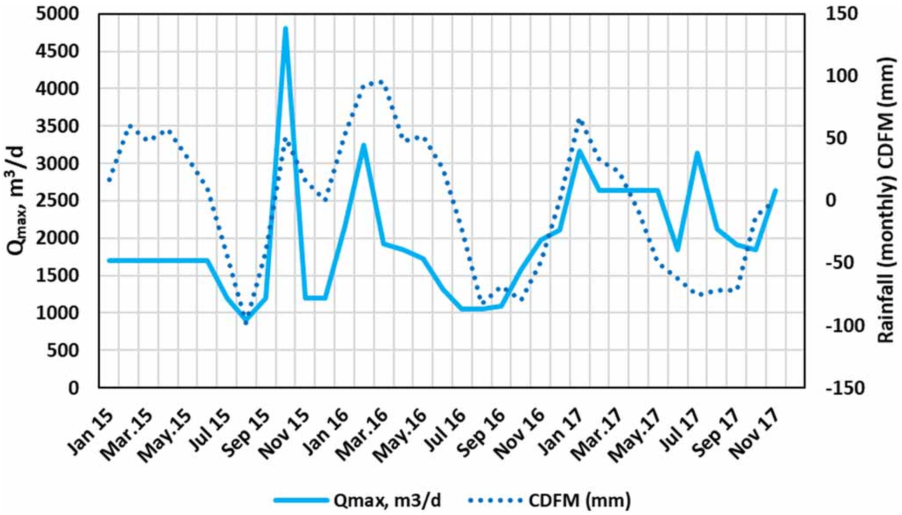

Figure 2 | Monthly variation of maximum daily flow and Cumulative Deviation from Mean (CDFM) of monthly rainfall between 2015 and 2017 in Terkos Advanced WWTP.

applications of poured-in-place concrete linings for manholes (EPA 2014). Old and leaky manhole covers should be replaced with watertight covers as they can be significantly contributing to I&I.

Dilution of wastewater due to I&I also affects sludge amount and quality. There have been occasions during sampling where no sludge was generated due to washout. Average sludge generation was estimated as 43.2 g dry solids per population equivalent (PE) per day assuming 0.12 kg COD contribution per person per day. The current practice is using mobile dewatering equipment to process the generated sludge and transport it to the big WWTPs where they are combined and go through final disposal at municipal solid waste landfills. Landfill disposal is not considered as a sustainable practice in the EU and many other countries any more (Kalderis *et al.* 2010). Hence, transporting sludge as supplementary fuel to licensed cement factories after thermal drying, biosolids composting and incineration alternatives have been evaluated by ISKI. Three incineration plants are currently planned for the disposal of WWTP sludge in the long run.

In recent years, natural treatment systems such as constructed wetlands have been increasingly used for wastewater treatment in small communities across Europe and North America (Kadlec & Wallace 2009; Wu *et al.* 2015). Compared to conventional treatment systems, their low construction cost, less energy demand, relatively easy operation and maintenance makes them suitable for wastewater treatment in rural areas (Wu *et al.* 2015).

Orucoglu constructed wetland system was designed as a hybrid system consisting of a septic tank followed by horizontal subsurface flow wetlands (HSFWs) and vertical subsurface flow wetlands (VSFWs) (Ayaz *et al.* 2008). The purpose of this design is to achieve effective nitrogen removal through nitrification and denitrification. As the water percolates through the pulse-loaded VSFW via unsaturated flow, oxygen is transferred to the wetland bed, allowing nitrification. In contrast, HSFWs operate under anoxic conditions and promote denitrification (Kadlec & Wallace 2009). Average monthly performance data for the Orucoglu constructed wetland during 2017 are given in Table 3.

Average removal efficiencies for COD, BOD_5 and TSS were 67%, 72% and 77%, respectively. As for the nutrients, 30% TN removal and 15% TP removal was achieved. In a hybrid constructed wetland system, if HSFWs are used before VSFWs, effluent recirculation is recommended to supply nitrified effluent to the HSFW system for denitrification. It has been shown that effluent recirculation enhances nitrogen removal (Ayaz *et al.* 2012; Vymazal 2013; Ávila *et al.* 2017). Hence, the TN removal performance of Orucoglu constructed wetland can potentially improve if the system is operated with effluent circulation.

When the constructed wetland system first started operation in 2009, the TP removal rate was reported to be 54% (ISKI, unpublished). The decrease in TP removal as the treatment system gets older is a typically seen phenomenon in wetland systems. Adsorption to sediments and filter material is the major TP removal mechanism in constructed wetlands (Kadlec & Wallace 2009). As the adsorption sites become saturated with time, TP removal efficiency rapidly declines unless the filter material is renewed each time. Thus, if efficient and continuous

Table 3 | Average monthly performance data for the Orucoglu constructed wetland in 2017

	COD (mg/L)		BOD$_5$ (mg/L)		TN (mg/L)		TP (mg/L)		TSS (mg/L)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
January	47	12	12	2	10.0	6.0	0.9	0.5	58	21
February	86	24	43	8	28.1	15.8	1.9	1.5	29	5
March	171	41	120	20	29.0	16.0	2.2	2.3	32	10
April	220	64	125	24	47.2	28.2	3.2	2.1	63	14
May	285	109	95	46	65.0	42.6	4.9	4.4	106	40
June	329	159	170	80	43.4	50.5	4.7	5.6	296	37
July	280	122	195	64	60.5	46.7	5.7	5.1	138	19
August	288	111	161	55	52.5	45.4	4.7	4.6	134	15
September	672	155	418	83	83.7	64.1	4.8	3.8	322	30
November	94	46	47	17	24.4	17.2	1.9	2.0	31	5
December	129	24	35	5	17.8	8.8	1.4	0.7	32	12

phosphorus removal is required, an additional treatment step such as chemical phosphorus removal might be an option.

More recently, hybrid wetland systems having free surface flow (FWS) wetlands have become more common. Inclusion of FWS wetlands together with VSFWs and HSFWs have been shown to improve TN removal efficiencies (Vymazal 2013). FWS wetlands can also improve TP removal efficiencies and keep their TP removal efficiency for a longer time, as they provide a wider sediment surface for adsorption and have more plants for phosphorus uptake. Hence, implementation of FWS wetlands within hybrid systems is recommended where there are no space constraints.

Besides mitigating the current I&I problem with the existing systems, ISKI plans to increase the number of constructed wetlands and package WWTPs with SBRs and upgrade the conventional WWTPs to advanced WWTPs for nutrient removal. Future research will focus on cost-effective design and integration of natural treatment systems for small communities that do not have access to main sewer lines.

CONCLUSIONS

- A thorough evaluation based on the capacity and performance of the existing wastewater treatment systems in rural districts revealed that a number of these systems are not operating at their optimum.
- I&I is a frequently seen problem, decreasing treatment performance and causing operational difficulties.
- Natural treatment systems such as constructed wetlands after septic tanks prove as a viable alternative in rural districts of Istanbul.
- Implementation of FWS wetlands within hybrid systems is recommended where there are no space constraints.

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