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CENTRALIZED VERSUS DECENTRALIZED WASTEWATER REUSE: A CASE STUDY FOR A TOURISTIC AREA

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Abstract: In this study, centralized and decentralized wastewater reuse alternatives were compared in terms of water saving potential and costs for a touristic case study area in Antalya, Turkey. The results of decentralized reuse revealed that the maximum water saving of a hotel is limited with either amount of wastewater generated or ratio of irrigated landscape area to bed number. The breakpoint for the case study area is estimated as 50 m^2/bed. As a result, in hotels where the ratio of irrigated area is less than 50 m^2/bed, wastewater reuse may not be cost effective. In case of centralized wastewater reuse, supply and demand is balanced and as a result 60% more water saving may be achieved for the case study area. Furthermore, investment and operation cost of centralized reuse are considerably low and the price of reclaimed water is lower than price of service water. The average unit price of reclaimed water used as irrigation water was found to be 1.29 €/m^3 in decentralized reuse, while the unit price was found to be 0.35 €/m^3 in centralized reuse; which brings forth an internal rate of return by 20% and a 5-year payback period.

Keywords: Centralized wastewater reuse, Decentralized wastewater reuse, Domestic wastewater reuse, Cost analysis, Net present value, Tourism sector

Merkezi ve Yerinde Atıksu Geri Kazanımının Karşılaştırılması: Bir Turizm Bölgesi için Örnek Çalışma

Öz: Bu çalışmada, merkezi ve yerinde atıksu geri kazanım alternatiflerinin, su tasarruf potansiyeli ve maliyeti, Antalya'daki bir turizm bölgesi için karşılaştırılmıştır. Yerinde atıksu geri kazanımı uygulamasında, geri kazanılabilecek su miktarının, oluşan atıksu miktarı ve otelin sulama yapılan yeşil alan büyüklüğünün, yatak sayısına oranı ile ilgili olduğu belirlenmiştir. İncelenen turizm bölgesi için, kırılma noktasının 50 m^2/yatak olduğu tahmin edilmiştir. Bu doğrultuda, sulanan yeşil alan büyüklüğünün yatak sayısına oranının, bu değerin altında olduğu otellerde, yerinde atıksu geri kazanımı ekonomik olmayabilir. Merkezi atıksu geri kazanım uygulanması durumunda ise, atıksu kaynağı ve ihtiyaç arasında denge sağlanabilecek, incelenen turizm bölgesi için yerinde arıtmaya kıyasla %60 daha fazla su geri kazanılabilecektir. Merkezi atıksu geri kazanımının ilk yatırım ve işletme maliyetleri de yerinde arıtmaya kıyasla oldukça düşük bulunmuş ve geri kazanılacak suyun maliyetinin, şebeke suyunun altında olacağı tahmin edilmiştir. Yerinde geri kazanım için, sulama suyu olarak kullanılabilecek arıtılmış suyun, ortalama birim fiyatı 1,29 €/m^3 olarak hesaplanmış, buna karşın, merkezi atıksu geri kazanımında, arıtılmış suyun 0,35 €/m^3 bedel ile otellere satılması durumunda, % 20 iç verim oranı ve 5 yıllık geri ödeme süresinin sağlanabileceği belirlenmiştir.

Anahtar Kelimeler: Merkezi atıksu geri kazanımı, Yerinde atıksu geri kazanımı, Evsel atıksu geri kazanımı, Maliyet analizi, Net Bugünkü Değer, Turizm sektörü

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1. INTRODUCTION

Tourism is a water-dependent sector, where the rate of water consumption is especially high when summer tourism on coastal zones are concerned. Irrigation is one of the main water consuming activities especially for those hotels with large irrigated landscapes (Hocaoglu 2017). Physical properties of the hotel, operational features and availability of an environmental management system are other important factors affecting water consumption (Bohdanowicz et al. 2007; Tortella and Tirado, 2011). In near future, water scarcity in the face of increasing water demand due to tourism is likely to drive the sector towards utilizing reclaimed domestic wastewater.

Basically, there are two different wastewater reuse approaches, as decentralized and centralized reuse. The decentralized reuse approach is mainly based on on-site separation of wastewater streams according to the level and type of pollution and possibility for utilization. Centralized wastewater reuse approach is based on end-of-pipe approach, which comprises collection of wastewater in a sewer, treatment in a central treatment plant and distribution of reclaimed water to users. Both approaches have their own advantages and disadvantages, and the most suitable method varies depending on conditions. For example, central wastewater reuse is advantageous in terms of (i) costs, as the costs decrease when the capacity increases (Roefs et al., 2017), (ii) controlled quality of reclaimed water (operated by professionals and analyzed quality) (Chu et al., 2004; Asano 2005). On the other hand, installation of an advanced treatment system and additional pipelines for reclaimed water is needed for central use, which is not only costly, but also investment decision is with the local authority. Instead, in the case of decentralized reuse, the investor can install the reuse plant at any time independent from the decision of the local authority. Furthermore, reuse of reclaimed water inside buildings, for example toilet flushing, is only applicable in grey water reuse, which is a case only in decentralized reuse approach.

In the last decade, decentralized sanitation approach has been well discussed in terms of concept (Wilderer and Schreff 2000; Tchobanoglous et al., 2004; Lamichhane 2007; Larsen et al., 2009; Larsen and Maurer, 2011, Joustra and Yeh, 2015), technologies (Otterpohl and Oldenburg 2003; Hong et al., 2005; Kujawa-Roeleveld and Zeeman, 2006; Singh et al.2015;) and cost (Onucyildiz et al., 2008; Wang et. Al., 2008; Chen and Wang, 2009; Libralato et al. 2012; Singh et al. 2015). Selection of the most suitable wastewater reuse method is case specific. The profitability of the decentralized wastewater reuse depends on investment, operation cost and price of service water. On the other hand, profitability of centralized reuse will be additionally affected by the site characteristics, such as topography and distance of the users from each other and the central plant. Wang et al. (2008) discussed the critical distance depending on the relationship between the cost for decentralized reuse system and centralized pipeline construction. They concluded that if the distance from the project site to the nearest access point of the centralized system is shorter than critical distance, then centralized wastewater reuse becomes more feasible. Similarly, Woods et al. (2013) developed a modified Decision Support System and applied to several scenarios and concluded that in case of limited existing capacity, greater elevation differences, and lower discount rates favour decentralized design and construction. Recently, Roefs et al. (2017) analyzed the sanitation systems under urban development uncertainty and concluded that conventional systems perform better than decentralized and hybrid sanitation systems if discounted lifetime costs are considered.

Most of the studies in the literature have been focused on economic issues of the decentralized and centralized reuse and water saving potential has been mostly overlooked. In a recent study by Gonzales and Ajami (2017) a comprehensive socio-hydrologic framework is developed to identify the effect of locally-driven factors such as water use efficiency, stress on existing supplies, and adaptation capacity potential on resilience. Additionally, in another recent study by Hocaoglu (2017) water balance between the available source and demand side is extensively evaluated for decentralized reuse in individual hotels.

In this study, not only costs but also the amount of water saved, which is one of the main issues in terms of sustainability but mostly overlooked in the studies in literature, have been compared for a touristic case study area by considering the balance between the source and demand. For this purpose, first a central wastewater treatment plant in a touristic area was selected, then individual wastewater treatment and reuse was compared with the central wastewater reuse in terms of amount of water to be saved and costs for hotels located in the vicinity of the central wastewater treatment plant.

2. MATERIALS AND METHODS

2.1 Case Study Area

The case study area consists of 24 hotels of various sizes and irrigated landscape areas in Antalya, Turkey. The hotels are located on a 3 km coastal line, the area is mostly flat with an elevation difference of maximum 4 m from the treatment plant.The region is very touristic. The weather is mostly dry in summer and partially dry in spring. The size (number of beds) and irrigated landscape area (m^2) of each hotel are given in Table 1. The smallest hotel in the study group has 24 beds and the largest has 2,618 beds with irrigated landscape areas ranging from 2,000 m^2 to 250,000 m^2. There is no specific correlation between the size of hotels and size of the landscape area, the ratio varying between 1 m^2/bed and 91 m^2/bed with 30 m^2/bed on average. There is a central biological wastewater treatment system servicing the area, consisting of coarse and fine screening, sand and oil removal, extended activated sludge reactor and clarifiers. The capacity of the treatment plant is approximately 23,000 m^3/day of municipal wastewater.

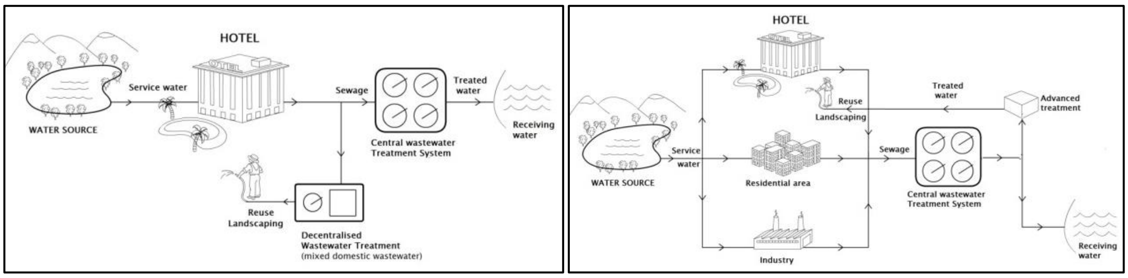
Table 1. Hotel Specifications

Hotels	Number of beds	Irrigated landscape area, m^2	Ratio of irrigated area, m^2/bed
Hotel 1	748	45,000	60
Hotel 2	1,183	60,000	51
Hotel 3	1,095	18,000	16
Hotel 4	620	24,000	39
Hotel 5	2,618	250,000	95
Hotel 6	574	40,000	70
Hotel 7	805	55,000	68
Hotel 8	420	13,000	31
Hotel 9	368	18,400	50
Hotel 10	1,094	20,000	18
Hotel 11	165	8,250	50
Hotel 12	276	25,000	91
Hotel 13	700	1,000	1
Hotel 14	700	2,000	3
Hotel 15	700	5,000	7
Hotel 16	700	1,000	1
Hotel 17	700	3,000	4
Hotel 18	700	1,000	1
Hotel 19	700	1,650	2
Hotel 20	700	2,000	3
Hotel 21	700	2,000	3
Hotel 22	700	2,000	3
Hotel 23	432	5,000	12
Hotel 24	64	2,000	31
AVERAGE	**1,397**	**48,344**	**30**
TOTAL	**34,924**	**1,208,600**	**-**

2.2 Scenarios

Central and decentralized wastewater reuse for 24 hotels is compared in terms of water saving potential and costs. The schematic illustration of the two scenarios is given in Figure 1. Scenario 1 (Figure 1a), decentralized treatment and reuse alternative, is based on individual on-site collection/treatment and reuse of mixed domestic wastewater for landscape irrigation. Water saving potentials of the hotels are calculated individually. The balance between the source (wastewater generated) and the demand (water needed for landscape irrigation) are analyzed first on a daily basis and then on an annual basis. It is assumed that the total amount of water consumed is treated as wastewater and all treated wastewater is suitable for irrigation. Simply put, if the amount of wastewater is less than the amount of water needed for landscape irrigation, then all domestic wastewater generated will be consumed for irrigation. In this case, maximum reuse potential will depend on wastewater availability and the rest will be drawn from service water. On the other hand, if the amount of wastewater is larger than the amount of water needed for irrigation than the maximum reuse potential will depend on the amount required for the said use. Details of on-site wastewater reuse mass balance calculations are well defined in Hocaoglu, 2017.

Centralized treatment and reuse alternative, Scenario 2 (Figure 1b), is based on the end of pipe approach, which is collection of wastewater in a sewer, treatment in a central treatment plant and distribution of reclaimed water to the 24 hotels in the case study area for irrigation purposes. In this alternative, since the amount of wastewater generated (supply) is larger than the amount of irrigation water required for the landscape (demand), it is assumed that those hotels, which currently use service water for irrigation, will switch to reclaimed water supplied from the central plant.



a) b)

Figure 1:
Schematic illustration of the scenarios, a) Scenario 1: decentralized on-site wastewater reuse, b) Scenario 2: centralized wastewater reuse

In order for the scenarios to be comparable in terms of costs, use of similar advanced wastewater treatment technology is assumed for both. For this purpose; Scenario 1 includes installation of MBR, then disinfection with UV and as a precaution excess chlorination, while Scenario 2 includes upgrading the available wastewater treatment technology to a membrane system and similar disinfection processes (ultrafiltration followed by available biological treatment, then disinfection with UV and as a precaution excess chlorination). The additional treatment in Scenario 2 is applicable only for the total amount that can be potentially reused by the hotels. The recovery efficiency of the ultrafiltration system is assumed to be 75% on average which is a typical performance value. In order to balance daily variations and attain peak need at day time, treatment system capacity is assumed to be 15% higher than that of average flowrates for both cases.

2.3 Water Consumption

Water demand for irrigation is calculated by using the estimated unit water requirement multiplied by the landscape area of each hotel. Then the sum of the daily water demand for the irrigated days is calculated in order to estimate the annual total demand for irrigation. Unit water requirement for irrigation is assumed to be equal in all hotels at 4.5 mm/m^2-day on average and irrigated days per year are assumed to be 210 (Hocaoglu, 2017). The amount of wastewater generated is estimated by using the number of beds, the average occupancy rate and the estimated daily wastewater generation per guest. The average occupancy rate is assumed to be equal in all hotels as 60% (a modest number for the area), and the average daily wastewater generation per guest is assumed to be 310 L/day-guest (Hocaoglu, 2017). The hotels are servicing as resort hotels and they are usually only servicing for about seven months (210 days) per year.

2.4 Cost Assessment

Cost assessment of both scenarios and their comparison is based on service water consumption (for domestic usage plus irrigation), domestic wastewater generation, and WWTP investment and operation costs. Price of water supplied to the hotels is €0.94/m^3 (March 2017 exchange rate applies). The exchange rate was ~4 TL/€. The cost of wastewater collection and treatment is fixed per bed in the area regardless of season and occupation rate; therefore, cost saving as a result of wastewater reduction is not applicable. Additional benefits of resource conservation were not considered.

Investment and operation costs of Scenario 1 for each hotel were estimated using cost curves developed for this study. The investment cost curve was prepared by using price quotations for various treatment capacities obtained from contracting companies operating in the market. The operation cost curve, on the other hand, was created by estimating the energy usage, chemical costs and personnel costs. Estimated energy usage varies between 140 kw/day for 75 m^3/day treated water and 1,700 kw/day for 1,000 m^3/day treated water at 0.1 €/kW. Chemical consumption costs are negligible. It is assumed that WWTP operation may require approximately 0.5 person-month and thus the personnel costs are estimated at 500 €/month.

In Scenario 2, estimated investment cost for transporting reclaimed water to the hotels along the 3 km coastal line was approximately 400,000 €, and additional investment cost of advanced treatment was also about 400,000 € which were the average costs obtained from the contracting companies (this is the additional investment costs for reclamation and does not include the cost of the existing biological treatment necessary to comply with discharge standards). Energy usage was based on 750 kwh/day at 0.1 €/kW. Chemical consumption cost was estimated at 35 €/day. Replacement costs were included in the internal rate of return calculations. The cost of membrane replacement was assumed to be one third of the initial cost of membrane module at the end of 10 years which were 400,000 € for Scenario 1 and 250,000 € for Scenario 2.

Net benefit is calculated by subtracting the initial investment and operating expenses from the benefit to be gained from the project. Net Present Value (NPV) is equal to the difference between the present value of the cash inflows and the present value of the cash outflows (**Hata! Başvuru kaynağı bulunamadı.**). NPV was calculated by discounting the total inflows and outflows over 15 years and discount rate is as assumed to be 10%, as a typical ratio for environmental studies.

$$NPV = -I_0 + \sum_{n=1}^{n} \frac{B_n}{(1+i)^n} \quad (1)$$

Here;

NPV: Net Present Value

I_0: initial investment cost

B_n: net benefit at time t, (benefits - costs)
i: discount rate
n: time at the end of analysis (in years)

Total cost for both scenarios is investment and operational costs; whereas, total benefit is the averted cost of service water which would otherwise be used for irrigation. The net benefit depends on the price of reused water.

3. RESULTS AND DISCUSSION

3.1 Comparison of Water Saving Potentials

Water saving for centralized and decentralized systems was compared in terms of additional service water required for irrigation. In Scenario 1, the decentralized system, landscape is irrigated with treated wastewater. If the amount of water required for irrigation is more than that of treated wastewater, then service water is used to make up for the difference; if not, then excess treated wastewater is discharged. In Scenario 2, the centralized system, wastewater from hotels are collected and treated at a central facility and then treated wastewater is sold as irrigation water.

Water saving potential of the decentralized reuse (Scenario 1) is calculated individually for each hotel depending on the balance between the wastewater generated and water needed for irrigation on a daily bases (Table 2). Total number of beds is 34,924 and the size of the total landscape area is 1,208,600 m^2. Estimated total water need for irrigation is 2,724 m^3 per day and 571,063 m^3 per year, while the amount of wastewater to be reused is 360,151 m^3 per year. The supply/demand balance is about +515 m^3/day, which means in total there is still excess wastewater that will not be utilized by the hotels. Meanwhile, in total 1,003 m^3/day additional service water will still be needed for irrigation. Accordingly, 210,912 m^3/year of service water is needed for irrigation.

On the other hand, in the case of central wastewater reuse (Scenario 2), a total of 571,063 m^3 per year irrigation water can be replaced with the reclaimed water, due to the fact that supply and demand is balanced in centralized wastewater recovery scenario. For example, the demand of a hotel with a bigger landscaped area but fewer beds that could potentially generate insufficient water for landscape irrigation will be balanced with the production from another hotel having excess wastewater due to a smaller landscaped area, thus lower irrigation need. This is schematically shown for two hotels in Figure 2. As a result, about 60% more water saving may be achieved by the centralized reuse scenario than the decentralized one for the case study area.

Table 2. Water saving potential of the decentralized reuse (Scenario 1)

Hotels	Demand: water required for irrigation, m^3/day	Source: available domestic wastewater, m^3/day	Balance, m^3/day	Potential saving, m^3/day	Need for additional service water, m^3/day	Water required for irrigation, m^3/year	Total saving, m^3/year	Need for additional service water for irrigation, m^3/year
Hotel 1	203	139	-63	139	63	42,525	29,217	13,308
Hotel 2	270	220	-50	220	50	56,700	46,208	10,492
Hotel 3	81	204	+123	81	0	17,010	17,010	0
Hotel 4	108	115	+7	108	0	22,680	22,680	0
Hotel 5	1125	487	-638	487	638	236,250	102,259	133,991
Hotel 6	180	107	-73	107	73	37,800	22,420	15,380
Hotel 7	248	150	-98	150	98	51,975	31,443	20,532
Hotel 8	59	78	+19	59	0	12,285	12,285	0
Hotel 9	83	68	-14	68	14	17,388	14,374	3,014
Hotel 10	90	203	+103	90	0	18,900	18,900	0
Hotel 11	37	31	-6	31	6	7,796	6,445	1,351
Hotel 12	113	51	-61	51	61	23,625	10,781	12,844
Hotel 13	5	130	+125	5	0	945	945	0
Hotel 14	9	130	+121	9	0	1,890	1,890	0
Hotel 15	23	130	+107	23	0	4,725	4,725	0
Hotel 16	5	130	+125	5	0	945	945	0
Hotel 17	14	130	+116	14	0	2,835	2,835	0
Hotel 18	5	130	+125	5	0	945	945	0
Hotel 19	7	130	+123	7	0	1,559	1,559	0
Hotel 20	9	130	+121	9	0	1,890	1,890	0
Hotel 21	9	130	+121	9	0	1,890	1,890	0
Hotel 22	9	130	+121	9	0	1,890	1,890	0
Hotel 23	23	80	+57	23	0	4,725	4,725	0
Hotel 24	9	12	+3	9	0	1,890	1,890	0
TOTAL	**2,724**	**3,245**	**+515**	**1,718**	**1,003**	**571,063**	**360,151**	**210,912**

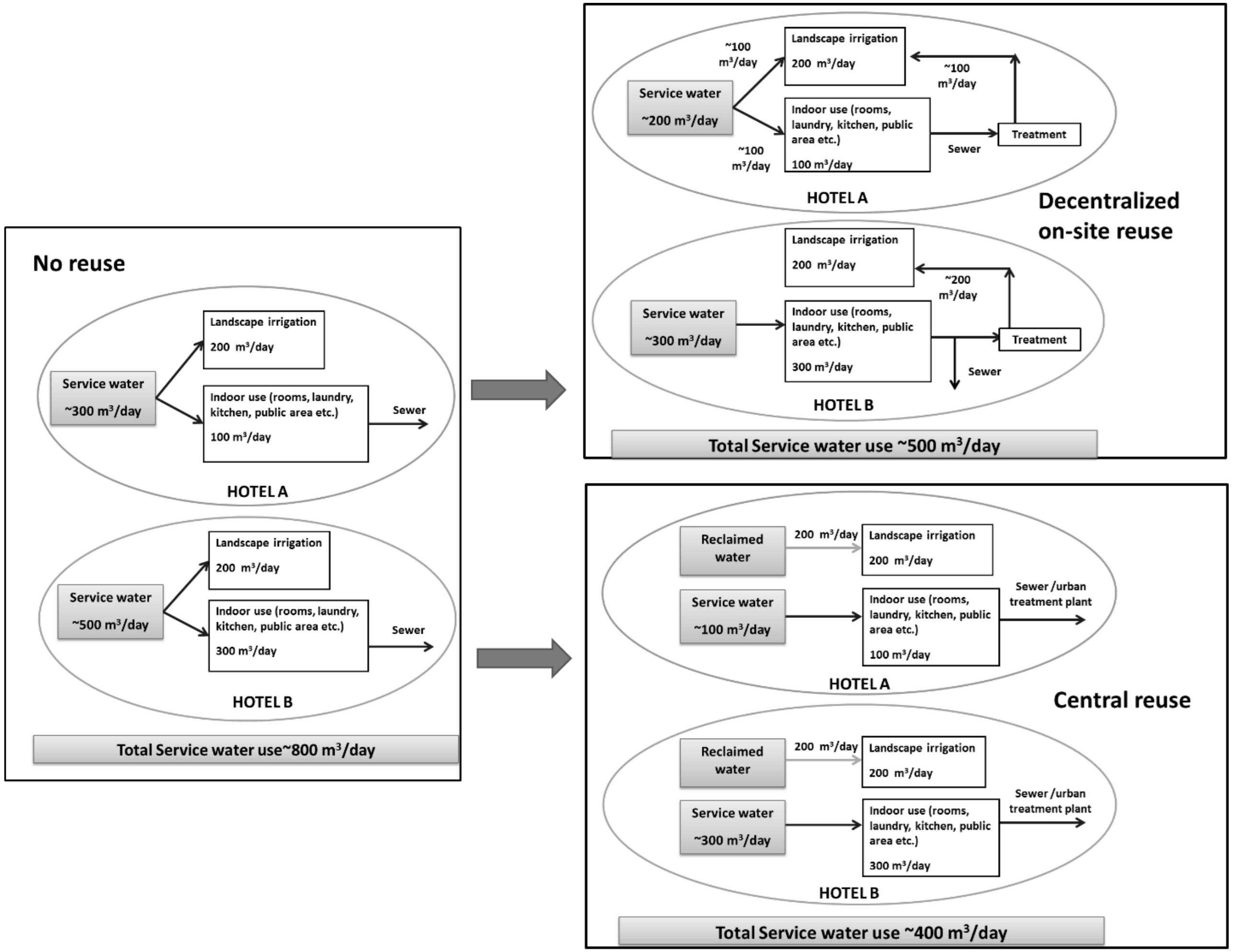


Figure 2:

Conceptual comparison of decentralized and centralized reuse solutions in terms of water saving

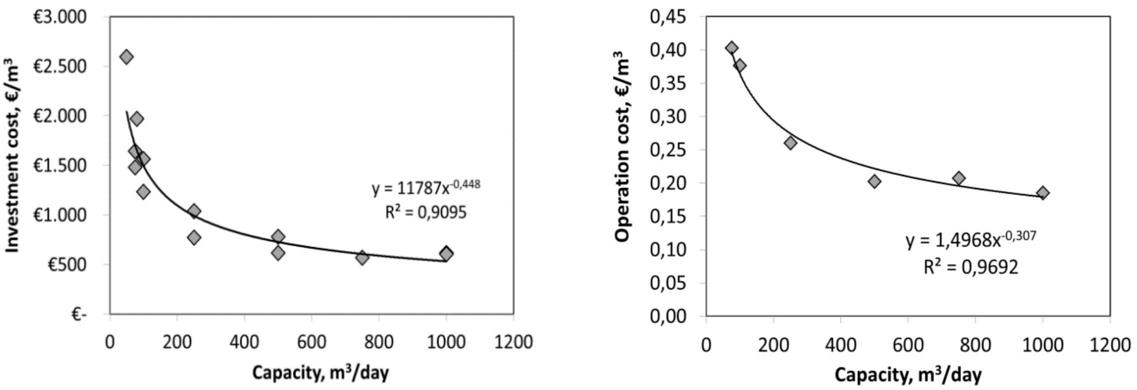
3.2 Cost Comparison

Investment and operation costs of decentralized reuse for each hotel was estimated by using the equations of the cost curves developed in this study (

). The treatment technology includes installation of MBR, then disinfection with UV and as a precaution excess chlorination. As seen from the

a, unit investment cost is approximately 2,500 €/m^3 for 50 m^3/day capacity, 1,200 €/m^3 for 100 m^3/day capacity. Cost decreases to 600 €/m^3 for 1,000 m^3/day capacity. Although, reduction in unit investment cost is expected when capacity increases, the difference is drastic for small sized treatment plants as in the case of decentralized reuse. Similarly, a significant reduction in operation cost is also observed when capacity increases (

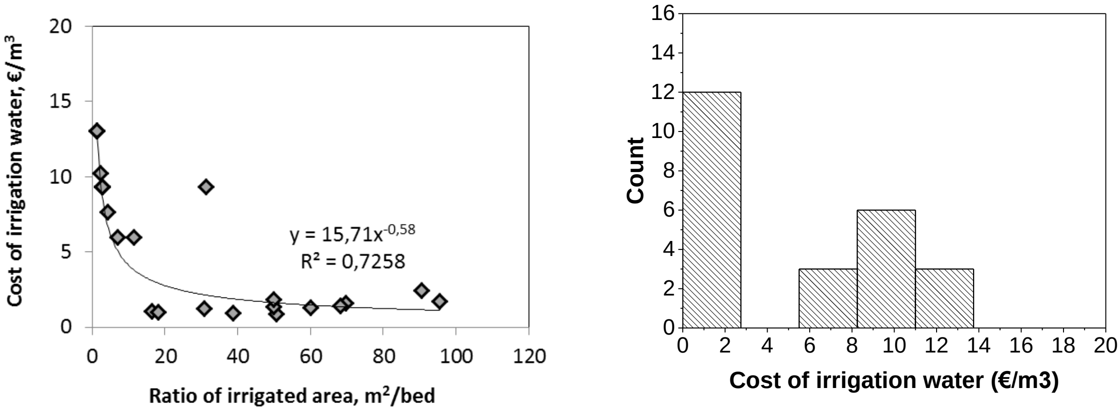
b). Unit operation cost is approximately 0.4 €/m^3 for 200 m^3/day capacity and decreases to approximately 0.17 €/m^3 for 1,000 m^3/day capacity.



a) b)

Figure 3:
Cost curves, a) investment cost, b) operation cost

The costs and benefits for each hotel in Scenario1 in which each hotel constructs and operates its own treatment plant are given in Table 3. Total investment of 4,147,115 € and annual operational cost of 304,386 € is required to treat 2,270 m^3 of wastewater annually. The annual cost of additional service water required where the amount of reclaimed wastewater falls short is 198,942 € and the total cost of landscape irrigation (reused water and service water) is 779,803 € per annum. Distribution of calculated unit price of irrigation water by irrigated landscape per bed is given in Figure 4a. The unit costs fall substantially as the irrigated landscape per bed gets bigger. Figure 4 can also be used to evaluate the profitability of decentralized wastewater reuse depending on the ratio of irrigated area of a hotel. If the unit price of service water is higher than the calculated cost of irrigation water in case of reuse, than reuse may be potentially cost effective. The breakpoint for the case study area is estimated as 50 m^2/bed. In hotels where the ratio of irrigated area is less than50 m^2/bed, wastewater reuse is not cost effective unless the water price is very high. In this case study, among the 24 hotels in the area, the unit price of irrigation is less than 3 € for 12 hotels; whereas, the cost for the remaining 12 hotels varies between 6 € to 13 € (Figure 4b). Clearly, an economic analysis of an obviously non-profitable situation with an alternative scenario is meaningless. Therefore, cost - benefit analysis for centralized and decentralized treatment & reuse - is continued with only 12 of the hotels with the unit price of irrigation less than 3 €.



a) b)

Figure 4:
Cost of irrigation water, a) variation of irrigation cost by ratio of irrigated area, b) histogram of irrigation water cost

Results of the profitability analysis are given in Table 4. In decentralized wastewater reclamation where the hotels install individual wastewater treatment plants, NPV of total investment cost is 2,407,383 €. On the other hand, in central wastewater reclamation, the Net Present Value of investment for reclamation and is 933,884 €. Under these circumstances, the unit price of irrigation water is higher than that of service water for decentralized wastewater reclamation.

Table 3. Costs and benefits of individual decentralized wastewater reuse

Hotels	Treatment capacity (m^3/day)	Investment cost, (€)	Operation cost, (€/year)	Annual cost of additional service water, €/year [1]	Annual cost of landscape irrigation (including service water), €/year [2]	Benefits, €/year [3]	Unit price of irrigation water (€/m^3) [4]	Unit price of treatment (€/m^3) [5]
Hotel 1	184	209,690	10,548	12,553	37,080	27,559	1.27	0.84
Hotel 2	291	270,068	13,558	9,897	41,459	43,585	0.90	0.68
Hotel 3	107	155,560	7,853	0	18,223	16,045	1.07	1.07
Hotel 4	143	182,332	9,185	0	21,341	21,393	0.94	0.94
Hotel 5	644	418,701	20,978	126,386	175,278	96,455	1.71	0.48
Hotel 6	141	181,177	9,128	14,507	35,713	21,148	1.59	0.95
Hotel 7	198	218,366	10,980	19,366	44,904	29,659	1.43	0.81
Hotel 8	77	129,982	6,582	0	15,247	11,588	1.24	1.24
Hotel 9	91	141,753	7,166	2,843	19,460	13,558	1.35	1.16
Hotel 10	119	164,875	8,316	0	19,308	17,827	1.02	1.02
Hotel 11	41	91,041	4,653	1,275	11,997	6,079	1.86	1.66
Hotel 12	68	120,939	6,133	12,115	26,311	10,169	2.44	1.32
Hotel 13	6	104,313	5,397	0	12,352	891	13.07	13.07
Hotel 14	12	149,580	7,626	0	17,598	1,783	9.31	9.31
Hotel 15	30	240,881	12,155	0	28,214	4,457	5.97	5.97
Hotel 16	6	104,313	5,397	0	12,352	891	13.07	13.07
Hotel 17	18	184,689	9,364	0	21,677	2,674	7.65	7.65
Hotel 18	6	104,313	5,397	0	12,352	891	13.07	13.07
Hotel 19	10	135,341	6,923	0	15,946	1,471	10.23	10.23
Hotel 20	12	149,580	7,626	0	17,598	1,783	9.31	9.31
Hotel 21	12	149,580	7,626	0	17,598	1,783	9.31	9.31
Hotel 22	12	149,580	7,626	0	17,598	1,783	9.31	9.31
Hotel 23	30	240,881	12,156	0	28,214	4,457	5.97	5.97
Hotel 24	12	149,580	7,627	0	17,598	1,783	9.31	9.31
TOTAL	**2,270**	**4,147,115**	**210.000**	**198,942**	**685,418**	**339,712**	**-**	**-**

[1] service water m^3/year* unit price of water
[2] annual operational cost + annual cost of additional service water + depreciation-investment/15years
[3] annual cost of service water (without reuse)–annual cost of additional service water (with reuse)
[4] cost of annual landscape irrigation with reuse/annual amount of wastewater used for irrigation
[5] depreciation (investment /15 years) + annual operational cost / annual amount of wastewater reused

Individual treatment and reuse is only profitable for Hotel 2 which has a large landscaped area (Table 3). The most important parameter affecting the profitability is the unit price of service water. If the price of service water rises and/or wastewater removal is charged based on the amount of water used rather than a fixed price per bed then profitability rates would change and individual wastewater reuse schemes would find wider use. In centralized wastewater reclamation, advanced treatment is installed at the municipal wastewater treatment plant and the reclaimed water is sold to the hotels for a price. Considering the additional investment and operation costs, as well as, installing ultrafiltration at the outlet of the existing treatment plant, reclaimed wastewater can be provided to the customers at a price of 0.35 €/ m^3 with a payback time of 5 years. Therefore, the centralized system would be profitable. In this case study, the hotels are close to each other (on 3 km coastal line) and to the central wastewater treatment plant, furthermore, the area is mostly flat with an elevation difference of maximum 4 m from the treatment plant, and the irrigation needs are high due to dry climate in summer season. Therefore, a centralized system is preferable to a decentralized system where each hotel builds its own treatment plant.

Table 4. Profitability analysis (12 hotels where benefits are relatively higher)

	Scenario 1 (decentralized reuse)	**Scenario 2** (centralized reuse)
Treatment capacity (m^3/day)	~2,100	~3,500
Water savings (m^3/year)	334,022	544,934
Investment cost (€)*	2,407,383	933,884
Operational cost (€)	875,315	253,217
Benefit (€)	2,396,403	1,450,685
Net Benefit (€)	(886,294)	397,468
Net Present Value	(695,913)	382,572
Internal Rate of return	N/A**	~%22
Cost of reclaimed water (€/m^3)	1.29	0.29
Price of service water (€/m^3)	0.94	0.94
Price of reclaimed water (€/m^3)	N/A	0.35
Payback time	N/A	5 years

*including membrane replacement after 10 years
**N/A: Not applicable as being not profitable

4. CONCLUSION

When deciding on the reuse approach, total amount of water saved is a case specific and critical parameter which should be evaluated thoroughly by considering the balance between the amount of available water and need for reclaimed water for each of the users. In this case study, according to the decentralized wastewater reclamation and reuse scheme, excess reclaimed water cannot be used by another hotel that does not generate enough wastewater to meet its irrigation requirements. Therefore, the maximum amount of water saving is limited with either the wastewater generated or the landscape area. As a result, a significantly more water saving, about 60%, may be achieved by the centralized reuse than the decentralized one for the case study area. It should be kept in mind that the total amount of irrigation water needed will depend on climate conditions. Comparison of unit cost of reclaimed water with the unit price of service water is the other critical parameter for selecting the optimum reuse alternative. In this case study area, when all hotels install and operate their own individual wastewater treatment and reuse systems, the cost of reclaimed water is estimated to be 1.29 €/m^3; whereas, the unit price of service water is 0.94 €/m^3. On the other hand, NPV of total investment of additional advanced treatment and operating costs are considerably less when all hotels benefit from a central wastewater treatment and reuse system. In this case, the cost of reused water is 0.29. €/m^3. A unit price of 0.35 €/ m^3 for reclaimed water leads to almost 22% internal rate of return and a 5-year payback period. Consequently, due to high water saving potential, considerably less investment and operational costs, and the price of reclaimed wastewater being less than the price of service water, centralized wastewater reuse is the more preferable option for the case study area where the area is mostly flat and the users are close to each other. The methodology used in this study may be used and expanded for other touristic areas having similar properties. Furthermore, models and/or programs which can be used to estimate the potential savings and costs will be very helpful for decision makers.

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REFERENCES

1. Asano, T. (2005). Urban water recycling, Water Science and Technology, 51 (8), 83-89.

2. Bohdanowicz, P., Ivo, M. (2007). Determinants and benchmarking of resource consumption in hotels—Case study of Hilton International and Scandic in Europe, Energy and Buildings, 39 (1), 82-95. doi:10.1016/j.enbuild.2006.05.005

3. Chen R., Wang X.C. (2009). Cost–benefit evaluation of a decentralized water system for wastewater reuse and environmental protection, Water Science and Technology, 59 (8), 1515-1522. doi: 10.2166/wst.2009.156

4. Tortella, B.D., Dolores, T. (2011). Hotel water consumption at a seasonal mass tourist destination. The case of The Island of Mallorca, Journal of Environmental Management, 92 (10), 2568-2579. doi:10.1016/j.jenvman.2011.05.024

5. Gonzales, P., Ajami, N.K. (2017). An integrative regional resilience framework for the changing urban water paradigm, Sustainable Cities and Society, 30, 128–138. doi:10.1016/j.scs.2017.01.012

6. Hocaoglu S.M. (2017). Evaluations of on-site wastewater reuse alternatives for hotels through water balance, Resources, Conservation and Recycling, 122, 43-50. doi:10.1016/j.resconrec.2017.01.022

7. Hong, S.W., Choi, Y.S., Kim, S.J., Kwon, G. (2005). Pilot-testing an alternative on-site wastewater treatment system for small communities and its automatic control. Water Sci. Technol. 51, 101-108. doi:10.2166/wst.2005.0356

8. Joustra, C., Yeh, D. (2014). Demand and source-driven prioritization framework towards integrated building water management (IBWM). Sustainable Cities and Society, 14, 114-125. doi:10.1016/j.scs.2014.08.009

9. Chu, J., Chen, J., Wang, C., Fu, P. (2004). Wastewater reuse potential analysis: implications for China's water resources management, Water Research, 38 (11), 2746-2756. doi: 10.1016/j.watres.2004.04.002

10. Kujawa-Roeleveld, K., Zeeman, G. (2006). Anaerobic treatment in decentralised and source-separation-based sanitation concepts, Rev. Environ. Sci. Biotechnol. 5, 115-139. doi:10.1007/s11157-005-5789-9

11. Lamichhane, K.M. (2007). On-site sanitation: A viable alternative to modern wastewater treatment plants, Water Sci. Technol. 55, 433-440. doi:10.2166/wst.2007.044

12. Larsen, T.A., Alder, A.C., Eggen, R.I.L., Maurer, M., Lienert, J. (2009), Source separation: Will we see a paradigm shift in wastewater handling?, Water Sci. Technol. 43, 6121-6125. doi:10.1021/es803001r

13. Larsen, T.A., Maurer, M. (2011). Source separation and decentralization. In:Wilderer, Peter (Ed.), Treatise on Water Science. Elsevier, Oxford, 203-229. doi:10.1016/B978-0-444-53199-5.00083-X

14. Libralato, G., Ghirardini, A.V., Avezzù, F. (2012). To centralise or to decentralise: An overview of the most recent trends in wastewater treatment management, Journal Of Environmental Management, 94, 61-68. doi:10.1016/j.jenvman.2011.07.010

15. Onucyildiz, M., Sevimli, M.F., Gorgulu, G. (2008). Evaluation of decentralized and centralized wastewater treatment plants, 8th International Scientific Conference on Modern Management of Mine Producing, Geology and Environmental Protection, SGEM, 1, 651-658.

16. Otterpohl, R., Braun, U., Oldenburg, M. (2003). Innovative technologies for decentralized wastewater management in urban and peri-urban areas, Water Sci. Technol. 48, 23-32.

17. Roefs, I., Meulman, B., Vreeburg, J. H. G., Spiller, M. (2017). Centralised, decentralised or hybrid sanitation systems? Economic evaluation under urban development uncertainty and phased expansion, Water Research, 109, 274-286. doi:10.1016/j.watres.2016.11.051

18. Singh, N.K., Kazmi, A.A., Starkl, M. A. (2015). Review on full-scale decentralized wastewater treatment systems: Techno-economical approach, Water Science and Technology, 71 (4), 468-478. doi: 10.2166/wst.2014.413.

19. Tchobanoglous, G., Ruppe, L., Leverenz, H., Darby, J. (2004). Decentralized wastewater management: challenges and opportunities for the twenty-first century, Water Sci. Technol 4, 95-102. doi.10.2166/ws.2004.0011

20. Wang, X.C., Chen, R., Zhang, Q.H., Li, K. (2008). Optimized plan of centralized and decentralized wastewater reuse systems for housing development in the urban area of Xi'an, China, Water Science and Technology 58 (5), 969-975. doi: 10.2166/wst.2008.456.

21. Werner, C. (2004). Ecological sanitation–principles, urban application and Challenges, Report at UN Commission on Sustainable Development, 12th Session - New York, 14-30 April, USA.

22. Woods, G.J., Kang, D., Quintanar, D.R., Curley, E.F., Davis, S.E., Lansey, K.E., Arnold, R.G. (2013). Centralized versus decentralized wastewater reclamation in the Houghton area of Tucson, Arizona, Journal of Water Resources Planning and Management, 139 (3), 313-324. doi: 10.1061/(ASCE)WR.1943-5452.0000249