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Cost analysis of alternative methods for wastewater handling in small communities

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Abstract

Wastewater collection and treatment is quite important for sustainable management. It would be uneconomical and impractical to provide sewer systems and separate wastewater treatment plants (WWTP) for small communities. The decision process in wastewater planning is rather important in terms of comparing the alternatives considered. The two important points in the management of wastewater at rural areas not connected to a sewer system are to develop an optimized operation strategy and to make sure that the complete system is environmentally and economically sustainable. In some regions, package treatment could be an alternative solution. However, in cases where there is an existing large WWTP, a cluster system, where sewage generated by small communities could be transported via conveyors to a centralized WWTP, could be employed. In this study, the wastewater treatment and disposal problems in small communities were addressed and an alternative wastewater handling scenario was proposed. Additionally, three wastewater handling scenarios were compared. As a case study, Gebze villages were selected.

Keywords: Wastewater collection and treatment; Cluster systems; Package treatment; Wastewater management; Small communities; Septage treatment

1. Introduction

One of the main objectives of a wastewater system consisting of a sewer network and a wastewater treatment plant is to protect the receiving medium (Erbe et al., 2002). In most developing countries, wastewater treatment and disposal is a matter of concern that needs to be addressed. The prospects for economic and social development, poverty and priorities for industrial investments are the main obstacles in making decisions about public wastewater facilities for small towns and rural communities. Since financing, constructing, operation and maintenance of sewer systems and wastewater treatment plants are quite costly, most developing countries (Bakir, 2001) including Turkey, avoid these projects. In sewage planning, the decision process is rather important in terms of comparing the alternatives considered. In the management of wastewater at rural areas not connected to a sewer system, the two important points are: (1) an optimised operation strategy for the wastewater system should be developed; (2) the complete system should be environmentally, socially and economically sustainable.

In Turkey, 45% of the total population is not served by a sewer system. Only 43 provinces have urban WWTPs with a total number of 129. Of those, 13 WWTPs are located in Istanbul Greater Metropolitan City, 14 WWTPs in Antalya city, on the south coast of the country, and 6 WWTPs in Kocaeli, a highly industrialized city in the vicinity of Istanbul (Arslan-Alaton et al., 2005). When the total population is considered, only about 15% of the total wastewater is treated in Turkey (Karpuzcu and Bayar, 1999). Where sewer systems are not available, municipalities are served by septic systems. Of all the municipalities, 28% are served by septic systems. Therefore, environmental pollution and related ecological problems are increasing. Unfortunately, these problems are not different for the other developing countries.

In areas served by municipal wastewater facilities, sewage is transported away from homes in large diameter gravity sewers to a central plant where it is treated and discharged into a waterway. In coastal areas, deep-sea discharge is common after pre-treatment. Outside of these areas, especially in remote regions and villages, most individual residences must rely on a septic tank and soil absorption field, or package treatment system, to dispose of their wastewater (LaGro, 1996). Cluster systems bridge the gap between these two systems in small

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communities where neither of the two systems is feasible. In many situations, centralized systems have actually made the problem worse and more complex, due to the operational problems, inadequate sewer systems and plants working under capacity (Bakir, 2001). Nevertheless, money is the main obstacle and therefore it is often not possible to build a centralized system.

Some new sanitation concepts have emerged over the past decade. Projects including urine separation, grey water collection and other sanitation systems, such as vacuum systems, have been implemented especially in Scandinavian countries (Oldenburg, 2005) and in some European countries (Nolde, 1999).

The initial step for wastewater treatment and disposal is to collect wastewater from its source and design and build a sewer system. In order to design an adequate sewer system, cities need to be planned according to a development strategy, which formulates a holistic vision for the city (LaGro, 1996). Unfortunately, this difficult task cannot be accomplished in developing countries. There are many examples of wastewater systems that do not relate to the local conditions. Because of poor urbanization, the sewer systems built are generally not technically suitable and economically much more expensive (Hoffmann et al., 2000). Mega cities, such as Istanbul, Ankara and Izmir in Turkey, have the same problems of poor urbanization.

When it is not feasible to collect wastewater with a suitable sewer system, it is almost impossible to treat wastewater with available wastewater treatment technologies. Consequently, other methods of disposal, such as septic systems, have appeared. Using septic tanks is not a proper disposal method but only a way of storing wastewater. However, it should be noted that if a septic tank is correctly designed, built according to design, properly operated and regularly emptied, it is an effective device to treat wastewater (Roomratanapun, 2001). Unfortunately, this is not the case most of the time. In a technical report published by EPA it was indicated that failing septic systems are the third most frequently cited source of groundwater contamination in the United States (USEPA, 1998). Stored wastewater needs to be carried to a suitable receiving medium at regular intervals. Unfortunately, in developing countries wastewater collected from septic tanks cannot be transferred and disposed according to statutory regulations. These collected wastewaters are generally denser than ordinary wastewater and therefore when the wastewater is discharged, it causes serious environmental and ecological problems in the receiving medium. Wastewater disposal must be managed effectively to safeguard public health, and protect the freshwaters from pollution. It must be reintegrated safely in the water cycle and accounted for in the water budget of the household, community, industry, and agriculture.

An alternative method of treating sewage for small communities is the individual package systems. The disadvantage of individual package systems is that these systems are more sensitive to the amount and content of wastewater compared to larger plants. In order to maintain the system's functions properly, the public, who get use of the package system, should be informed by means of written and visual media, regularly. The users should also be, to some extent, responsible for their production of wastewater.

All these problems call for a shift from centralized large wastewater treatment systems to cluster wastewater systems (El Gawad and Butter, 1995). Cluster wastewater systems are used to store, collect, treat and dispose of relatively small volumes of wastewater, generally from residential areas, touristic villages and vacational districts that are located relatively apart from each other. These systems could therefore be an alternative treatment and disposal method, which would result in higher treatment levels, greater reliability and more flexibility (Tao, 1999). Domestic wastewater of industrial areas could be collected if needed. It is believed that in most developing countries, cluster wastewater systems are the most appropriate, environmentally responsible and least costly treatment options and they allow maximum flexibility in planning for future growth. In brief, the advantages of cluster systems can be numbered as follows;

- Cost
- Flexibility in land use
- Maintenance
- Environmental protection.

Additionally, the European Union obliges the Member States to comply with certain objectives with respect to wastewater collection and treatment. According to the regulation (EEC, 1991), all rural regions with a population of over 2000 must have an environmental infrastructure that enables their wastewater to be adequately treated by the end of the year 2005 (Adenso-Diaz et al., 2005). Therefore those who are responsible for taking necessary actions should consider various wastewater collection, treatment and disposal alternatives, which include the usage of existing treatment plants. One of the most important criteria in the evaluation process of such alternatives is cost (Adenso-Diaz et al., 2005).

The aims of this paper are, therefore, to address the wastewater treatment and disposal problems for small communities, to introduce an alternative wastewater handling scenario called the 'cluster system' and to offer an optimum wastewater system for small communities having a population up to 3000. Twenty-two villages of Gebze town were selected as a case study considering the local, technical and environmental conditions. This is very important, as the performance of a specific system depends on its construction, use, and maintenance. In the case study, it was assumed that the selected villages are 25 km away from an existing WWTP, and the treatment plant was designed to be maintained for a period of 25 years.

2. Method

In this study, a methodology for calculating wastewater handling costs for small communities was developed. Since constructing sewer systems and WWTPs for small communities is quite costly, alternative methods, such as package treatment options or cluster wastewater systems; were considered in this study. In cluster wastewater systems, wastewater stored in septic tanks is collected with conveyors, esp. from scattered housing, and then transferred to an existing large regional WWTP. The methodology developed in this study is a cost estimation method related to handling wastewater for small communities. The following three cases were considered:

Case 1. -classical sewer and WWTP system

- Construction of a sewer system for each small community,
- Construction of a collector from residential areas to a WWTP. In this case, it was assumed that there is a large WWTP within 25 km working under capacity;

Case 2. -cluster system

- Construction of septic tanks for households in each community,
- Collection of sewage from septic tanks and transporting sewage via conveyors to a WWTP. Here, it was also assumed that there is a large WWTP within 25 km working under capacity;

Case 3. -package treatment system

- Construction of an individual package treatment system for each small community.

It was considered that these systems would function and could be maintained satisfactorily for duration of 25 years and comparisons were done accordingly. The maintenance costs included the cost of a minimum number of workers and the costs of possible gradual obsolescence. In the villages close to Istanbul, annual population increase is around 1–2%, according to the statistics (SIS, 2000). For the calculations, the possible population increase was chosen to be 2% per year. Wastewater produced per capita was chosen as 100 L day^{-1}. Table 1 summarizes the costs used in the calculations. The cumulative costs were calculated for each case, as shown in Eq. (1)–(3). MS Excel was used for the calculations.

For Case 1, the right hand side of Eq. (1) shows the sewer system construction costs within the residential areas, from the residential areas to the main collector and from the main collector to the WWTP. The final item of the equation shows the treatment costs for each community. It was assumed that the WWTP would be operated and maintained satisfactorily for duration of 25 years.

For Case 2, the calculation (Eq. (2)) was based on the construction of septic tanks for households and the transportation of sewage via conveyors from residential areas to the WWTP. Treatment costs for each community for duration of 25 years of operating time were also added.

Finally for Case 3, the calculation (Eq. (3)) was based on the establishment of a package treatment system with its concrete bottom layer, the electricity supply required, and the construction of the necessary basic sewer system. The second and third items on the right hand side of the Eq. (3) shows the operating and maintenance costs for each community, and the sewer system construction cost from the package treatment unit to the main sewer collector.

Table 1
Costs related to the construction and maintenance of sewer system, septic tanks and package treatment systems

	Parameters	Unit[a]	Population	Cost
c_1	Sewer system construction cost in residential area	€/m	–	36.36
c_2	Sewer system construction cost outside residential area to main sewer system collector	€/m	–	39.39
c_{3m}[b]	Treatment cost	€/m^3	0–500	0.36
			500–1000	0.30
			1000–1500	0.24
			1500–3000	0.18
c_4	Septic tank construction cost	€/P	–	60.61
c_5	Sewage transportation cost via conveyors	€/m^3. km	–	0.06
c_{6m}	Construction of an individual package treatment system	€/P	0–500	60
			500–1000	50
			1000–1500	40
			1500–3000	30
c_{7m}	Maintenance of an individual package treatment system	€/P. mon	0–500	2,5
			500–1000	1,1
			1000–1500	0,8
			1500–3000	0,6
c_8	Sewer system construction cost of main collector outside residential area	€/m	–	42.00

[a] The costs were calculated in € and it was accepted that 1 € equals to 1.7 YTL (New Turkish Lira). Inflation was ignored.
[b] m stands for different population bands.

$$\mathrm{TC}_1 = \left(\sum_{i=1}^{n} P_i \cdot k \cdot c_1\right) + \left(\sum_{i=1}^{n} d_{1i} \cdot c_2\right) + (Lc_8) + \left(\sum_{i=1}^{n} P_i \cdot Q \cdot D \cdot c_{3m}\right) \quad (1)$$

$$\mathrm{TC}_2 = \left(\sum_{i=1}^{n} P_i \cdot c_4\right) + \left(\sum_{i=1}^{n} \frac{P_i \cdot Q \cdot c_5 \cdot D \cdot d_{2i}}{10^3}\right) + \left(\sum_{i=1}^{n} P_i \cdot Q \cdot D \cdot c_{3m}\right) \quad (2)$$

$$\mathrm{TC}_3 = \left(\sum_{i=1}^{n} P_i \cdot c_{6m}\right) + \left(\sum_{i=1}^{n} \frac{P_i \cdot D \cdot c_{7m}}{30}\right) + \left(\sum_{i=1}^{n} P_i \cdot k \cdot c_2\right) \quad (3)$$

Notations used in the equations are as follows:

TC_1 total cost of Case 1, €

D operation time, day
TC_2 total cost of Case 2, €
c_1 sewer system construction cost in residential area, €/m
TC_3 total cost of Case 3, €
c_2 sewer system construction cost from residential area to main sewer collector, €/m
n number of remote areas
P_i population of each residential area, P
c_{3m} treatment cost, €/m^3
k length of sewer pipe per capita, 4 m/P
c_4 septic tank construction cost, €/P
d_{1i} distance of each residential area to main sewer system collector, m
c_5 sewage transportation cost via conveyors, €/m^3.km
d_{2i} distance of each residential area to treatment plant, m
c_{6m} package treatment plant construction cost, €/P
L length of main sewer system collector to treatment plant, m
c_{7m} package treatment plant operation cost, €/month
Q average daily flow, m^3/P.day
c_8 sewer system construction cost of main sewer collector, €/m

3. Case study

3.1. Background

Gebze town is situated in the north-western part of the city of Kocaeli, covering an area of 772 km^2 and having a total population of 443,000 including the villages. Gebze is located at an important junction on the Silk Road. Therefore, in every stage of history, this town has attracted people. It should also be noted that the town is located on the border of Istanbul, the biggest city of Turkey. Today, Gebze, with 548 different industrial companies, is a big industrial area. Consequently, the population varies from day to night, since many people who work in Gebze live in Istanbul. At the moment, management of the sewer system of Gebze town is performed by the Gebze Municipality. The sewage is collected via a combined sewer system, where possible, and then discharged to the Kocaeli sewer collector. However, most of the villages of Gebze discharge their wastewaters to the receiving medium without any treatment.

In this study, the calculations were carried out for 22 villages of Gebze. The population of each village (SIS, 2000), their distances to the town (Gebze) and the city (Kocaeli) are given in Table 2. The reason for the selection of this area was because the area is highly populated and accommodates residential areas and many industries.

Table 2
Name of the villages of Gebze, their distances to Gebze town and city of Kocaeli (SIS, 2000)

Name of village	Population (2000)	Distance to town (km)	Distance to city (km)
Ahatli	138	45	90
Balcik	1.156	9	50
Cumakoy	1.156	17	66
Cerkesli	991	18	43
Demirciler	609	14	45
Denizli	1.174	18	70
Durakli	205	4	52
Elbizli	111	50	40
Eskihisar	325	6	40
Hatiplar	294	42	91
Kadilli	483	20	65
Kargali	459	38	75
Koseler	417	17	45
Mollafenari	854	14	60
Muallimkoy	879	7	45
Mudarli	461	33	82
Ovacik	416	27	72
Pelitli	1.598	11	55
Tavsanli	2.011	8	45
Tepecik	395	23	55
Tepemanayir	224	52	70
Yagcilar	210	32	50

4. Results

In this study, firstly a cost analysis method was developed for the villages of Gebze town. It was assumed that the distances from the villages to the existing treatment plant are within 25 km. The operation time was changed from 1 to 25 years. Fig. 1 shows the contour maps of the total costs of three developed scenarios (TC_1, TC_2, TC_3), for different distances and times. By using these graphs, the costs can be easily obtained for any scenario, time or distance. The color scale (Fig. 1d), changing from black to white, corresponds to the costs which change from 4 to 20 million €. Both for the first case (Fig. 1a) where use of a sewer system was advised and for the second case (Fig. 1b) where the use of septic tanks and conveyors was advised, the total costs increased as time and distance increased. As can be seen from the slopes of Fig. 1a and b, distance has a greater effect on the cost, when compared to time. On the contrary, for case 3 (Fig. 1c), where a package treatment system was advised, there was no effect of distance on the total costs. Time is the main parameter that affects the cost.

For easy interpretation, Fig. 2 shows the lowest cost scenario according to time and distance. As can be seen, the lowest cost scenario on the upper left region with blackish color is TC_1 among the three cases. The bottom region with light-grey color, for years 1 to ~10 and for all distance values, shows that TC_2 is the most preferable scenario among the others. In the rest of the graph, the lowest cost can be obtained by using the scenario TC_3.

The distance from the main sewer system collector to the WWTP is 7 km for the 22 villages of Gebze. In the first analysis, operating time was changed from 1 to 25 years. The total costs were calculated using the equations given above and are presented in Fig. 3. As can be seen from the graph, for the first 9 years, Case 2 was the most economical scenario, however between the years 10 and 19, Case 3, and for the

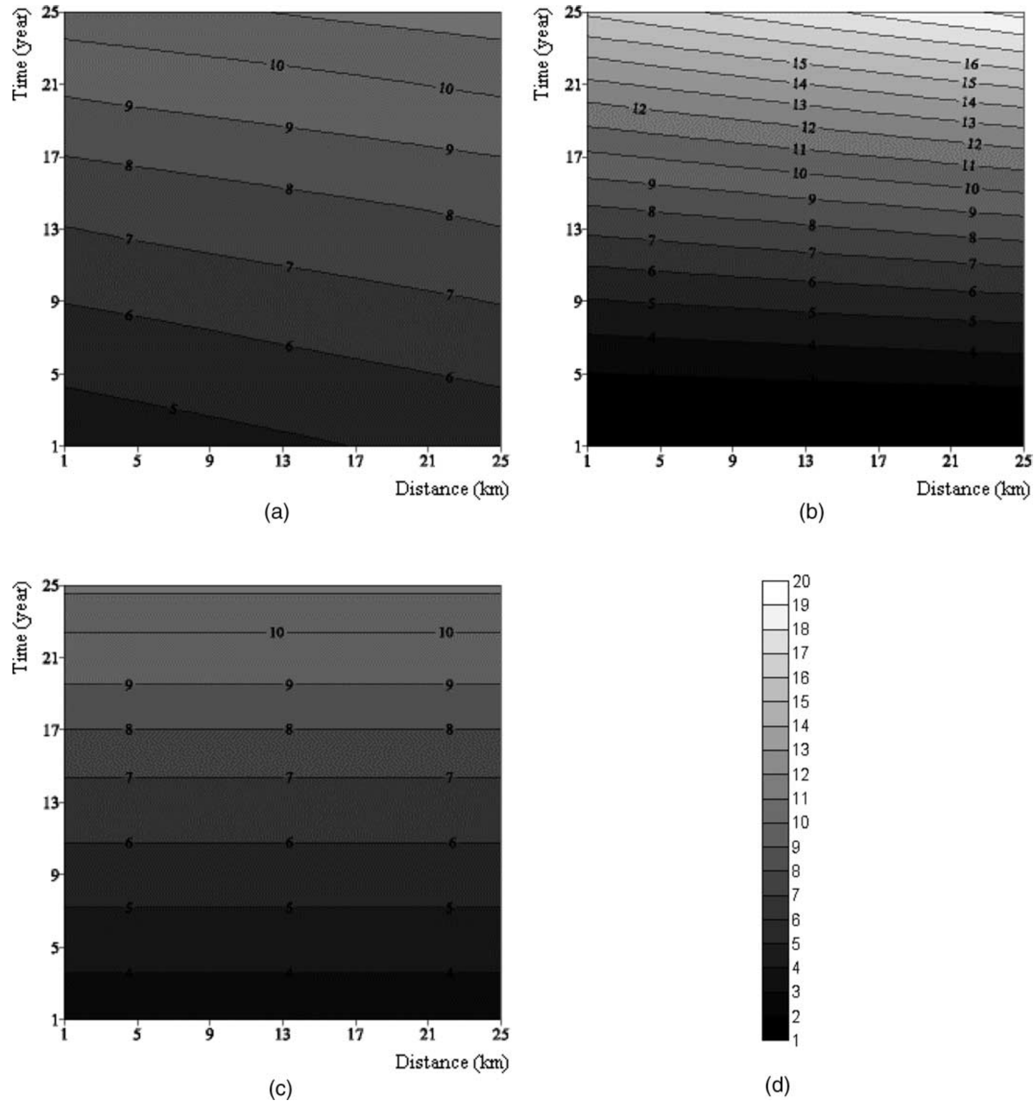

Fig. 1. Cost contour maps of three cases according to time and distance, in million €. (a) TC_1, (b) TC_2, (c) TC_3, and (d) color scale.

operation time up to 25 years, Case 1 was the economical option for the villages of Gebze. The above results have shown that the cluster system could be an efficient system for small communities when the distance is equal to or less than 7 km and for operation times up to 20 years. Based on the foreseeable operating time, the decision as to which option will be applied among the 3 cases offered in this study can be easily made using this graph (Fig. 3).

In the second analysis, operating time was kept constant at 25 years. The distance from the main sewer system collector to the treatment plant was changed between 3 and 25 km, and total costs were calculated accordingly and presented in Fig. 4. As can be seen from the graph, for the first 16 km, Case 1 was the most economical scenario. However, above 16 km, Case 3 was the most feasible option. On the other hand, Case 2 is obviously not a suitable option, as the costs of collecting sewage from septic tanks and carrying it to a main collector for duration of 25 years would be extremely expensive.

5. Conclusions

Although, for sustainable development, it is necessary to include a wide range of criteria (such as, environmental, technical, hygienic, and socio-cultural parameters) in the decision process, in most developing countries, economy is the most important criterion. Thus, there is a need to develop a model for finding appropriate solutions for wastewater handling for small communities. Such a model should be an operational tool, and be easily adapted to the local planning processes. The model should also be applicable to sustainable sewage management. The method developed in this study was used to assess three alternative solutions considering environmental, technical and most importantly, economic parameters. In order to show the performance of the model, the villages of Gebze were selected as an example.

Cluster systems could be a solution for small community wastewater problems, where constructing sewer systems

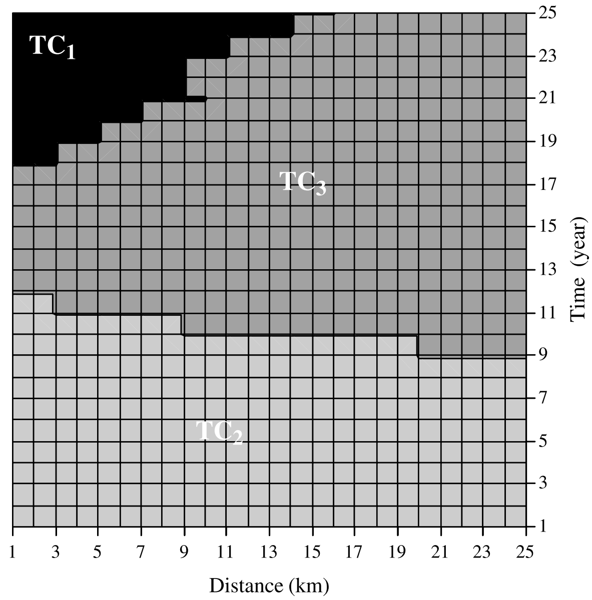

Fig. 2. Map showing the lowest cost scenarios according to time and distance.

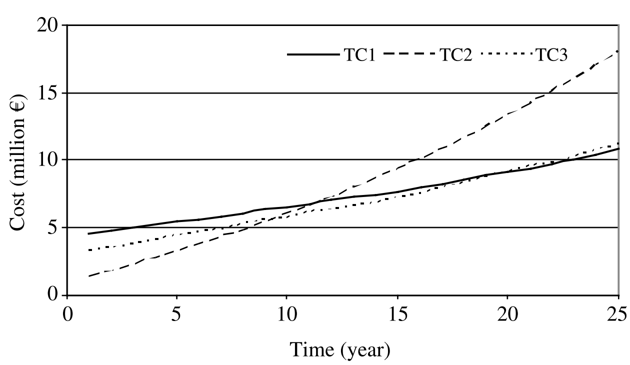

Fig. 3. Total costs of the 3 cases according to operation time.

and conventional central treatment plants or operating an individual package treatment system are not practical or affordable. Package treatment plants may not meet increasingly stringent water quality limits for wastewater discharge to the receiving medium. Cluster systems can be used where there is an existing WWTP working under capacity, and the wastewater load can be increased by the wastewater

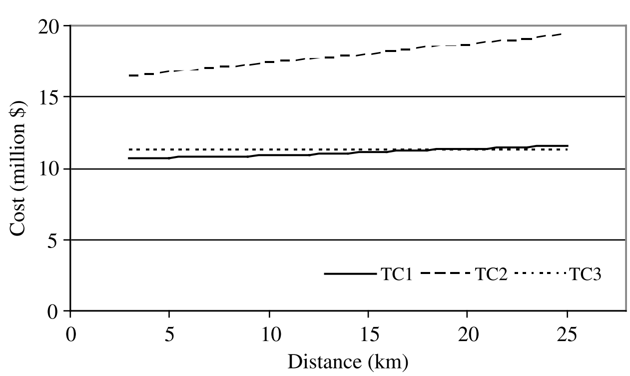

Fig. 4. Total costs of the 3 cases according to distance of main collector to WWTP.

transported via conveyors. In this way, the treatment efficiency of the treatment plant can be increased. The main benefit of cluster systems is that they can be constructed faster than in-ground systems and offer more flexibility to deal with rapidly changing land use plans. Another advantage of cluster systems compared with conventional collection and treatment systems is that these systems require minimal operational and maintenance costs. Consequently, this method is recommended especially for communities with a population of less than 3000 people living nearby an existing regional WWTP for cost optimization.

According to the case study carried out for this study, the cluster system is the most feasible method for wastewater handling for maintenance periods up to 10 years. However, for a long-term plan, package treatment could be an option. The proposed cost analysis method can easily be adapted for other small communities and remote regions. However, the choice of the best solution will differ from one place to another, as the final assessment should depend on local technical, environmental, and economical aspects.

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References

Adenso-Diaz, B., Tuya, J., Goitia, M., 2005. EDSS for the evaluation of alternatives in waste water collecting systems design. Environmental Modelling and Software 20, 639–649.

Arslan-Alaton, I., Gurel, M., Eremektar, G., Ovez, S., Tanik, A., Orhon, D., 2005. Prevailing situation of Turkish urban wastewater treatment plants. Proceeding of 1st ZERO-M Conference on Sustainable Water Management, Istanbul, Turkey, pp. 639–649.

Bakir, H.A., 2001. Sustainable wastewater treatment management for small communities in the in the Middle East and North Africa. Journal of Environmental Management 61 (4), 319–328.

EEC, 1991. CouncilDirective 91/271/EEC concerning urban waste-water treatment. Official Journal of the European Community L135, 40–52.

El Gawad, H.A., Butter, J.H.C., 1995. Clustering of towns and villages for centralised wastewater treatment. Water Science and Technology 32 (11), 85–95.

Erbe, V., Risholt, L.P., Schilling, W., Londong, J., 2002. Integrated modelling for analysis and optimisation of wastewater systems — the Odenthal case. Urban Water 4, 63–71.

Hoffmann, B., S, B., Nielsen, M., Elle, S., Gabriel, A.M., Eilersen, M., Henze, S., Mikkelsen, 2000. Assessing the sustainability of small wastewater systems: a context-oriented planning approach. Environmental Impact Assessment Review 20, 347–357.

Karpuzcu, M., S. Bayar, 1999. The extent of environmental pollution in Turkey. In: The Proceeding of Symposium on the Priorities of Environmental Pollution in Turkey III, Gebze Institute of Technology, 18–19 November, 1:1–8 (in Turkish).

LaGro Jr., J.A., 1996. Designing without nature: unsewered residental development in rural Wisconsin. Landscape and Urban Planning 35 (1), 1–9.

Nolde, E., 1999. Greywater reuse systems for toilet flushing in multi-storey buildings-over 10 years experience in Berlin. Urban Water 1 (4), 275–284.

Oldenburg Sanitation as a resource management system. Proceeding of 1st ZERO-M Conference on Sustainable Water Management, Istanbul, Turkey, pp. 7–10.

Roomratanapun, W., 2001. Introducing centralised wastewater treatment in Bangkok: a study of factors determining its acceptability. Habitat International 25, 359–371.

State Institute of Statistics (SIS), 2000. Demographic Report.

Tao, Y.X., Hills, P., 1999. Assessment of alternative wastewater treatment approaches in Guangzhou, China. Water Science and Technology 39 (5), 227–234.

USEPA, 1998. National Water Quality Inventory: 1998 Report to Congress. EPA 305(b) Report. USEPA, Washington, DC.