Assessment of decentralized wastewater management systems in Finland

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ABSTRACT

In order to combat eutrophication of inland and coastal waters and take advantage of the high practical and technical performance associated with centralized systems, there has been a tendency in Finland to expand centralized wastewater network coverage to rural areas despite high cost barriers. The objective of this research is to identify and assess the appropriate wastewater treatment options for rural Finland by surveying the current options (conventional centralized, source separating and non source separating decentralised systems at a scale of 20 - 100 households, source-separating onsite sanitation). In examining the assumptions underlying the preference for conventional centralized networks, this research concludes that decentralized options offer the same benefits at a potentially much lower cost to system users and owners. Moreover, evidence from this research indicates that household cooperatives are able to finance and operate decentralised wastewater treatment plants in a sustainable and cost-effective way. The research is within a research project of Wageningen University, i.e. the Global Sanitation Assessment (GSA), which strives to assess the adoption and operational performance of non-conventional systems in reference to conventional technologies.

INTRODUCTION

This research contributes to the current discussions about the future development of wastewater treatment in sparsely populated areas in Finland. Specifically, the research focused on whether emphasis should be placed on centralization and whether the scope of decentralized options should be expanded to include source separation.

Finland's population of approximately 5 million is concentrated in the south and southwest, resulting in a population density varying between 2.2 km^2 (in Lapland) to 205 inhabitants per km^2 in the capitol province. Despite the relatively clean status of Finland's surface waters [1], eutrophication has continued to be a problem with inland and coastal waters despite improvements in point source pollution since the 70s [1,2].

Urban areas, which contain about 80% of the population, are connected to wastewater treatment networks. Low population density however, makes infrastructure development and service provision in rural areas costly. Domestic wastewater from these areas has been identified as contributing to eutrophication and it is estimated that phosphorous discharges to water in rural areas are 50 % higher per inhabitant than in urban areas [1]. Though still widely used in rural areas, septic tanks alone no longer meet legal requirements. The need to decrease wastewater pollution in rural areas has been recognized. In addition to the targets set by the 3rd national Water Protection Program for 2005 adopted in 1998, the Onsite Wastewater System Decree 532/2003 (OWSD) has brought about improvements [1] in discharge from systems treating wastewater for a PE of less than 100. The treatment requirements are based on calculations of environmental loads (g/cap/day) for BOD, phosphorous, and nitrogen. While new buildings have to meet requirements immediately, the OWSD allows existing buildings a 10-year transition period until 2014 [3]. It also reinforces property owners' responsibility of sanitation outside of sewage networks [4].

Due to the OWSD, there is currently activity around the development of wastewater treatment for rural areas on all levels: centralized sanitation, decentralized sanitation, and onsite sanitation. Centralized sanitation using conventional treatment is generally the preferred method and these networks are expanding to connect rural areas. Benefits of centralization include the stability of larger influent amounts, high treatment levels and constantly improving technology, and the existence of effluent quality monitoring systems. However, the cost of connecting rural areas is often high due to the large distances between the area of connection and the existing network or even between houses in rural areas [6].

Decentralized sanitation can be described as wastewater treatment with networks serving population equivalents (PE) of less than 100. Recent promotion in cases where centralized sanitation is not possible has created a rapidly developing market for small scale conventional treatment plants. In other European countries, source separation of wastewaters in decentralized systems (DESAR) is being used in both rural and urban developments [6]. Depending on the technology and the fractions separated, benefits can include decreased water use, lower required treatment efficiencies, and the availability of fertilizers in the form of urine and compost. Although source separation is promoted at the onsite sanitation system level, DESAR systems are not, despite the potential to offer less populated areas of Finland a sanitation solution that could help control nutrient loading of sensitive inland waters.

METHODS

RESEARCH OBJECTIVE [6]

To identify and assess the appropriate wastewater treatment options for rural areas in Finland to see whether decentralized sanitation systems offer a solution by surveying the current sanitation system options (conventional centralized, DESA, DESAR and source-separating onsite sanitation), analyzing the positions of various stakeholders, identifying the drivers and barriers to certain technology choices, and assessing the in-the-field performance.

RESEARCH QUESTIONS

1. What are the options for wastewater collection and treatment systems in Finland at the centralized, decentralized, and onsite system level?
2. What are the drivers and barriers (legal, environmental, financial and social and managerial) regarding the various technology choices?
3. What is the comparative performance of wastewater treatment systems for rural areas in Finland?

SITE SELECTION

In order to assess the wastewater treatment options available for rural Finland, different examples of implemented options were included in the assessment. The terrain and conditions were controlled for by choosing sites along the southern coast of Finland. Options represented the various levels of centralization, as well as both source-separating systems and conventional technology options. The decentralized systems all use the same treatment technology and have a cluster of households connected to a decentralized treatment plant. Both of the onsite system areas are made up of different types of individual onsite treatment systems and technologies.

Table 1. Site Descriptions.

Site	Location	Description	Technology	Level of Centralization	Source Separating?
Suvisaaristo	Espoo Archipelago	sparsely populated community on the fringe of Espoo	Low Pressure Sewer network connecting households to Espoo municipal wastewater treatment network through the efforts of a local water cooperative	Centralized	No
Vessö and Emäsalo	Porvoo Archipelago	two sparseley populated islands	Several decentralized systems using Sequencing batch reactor technology connecting a varied number of households. Treats mixed wastewaters.	Decentralized	No
Bromarv's Ekoby	Tammisaari Archipelago	new apartment housing complex within rural community	Sequencing batch reactor with urine diversion and urine treatment. Urine reused as fertilizer to local farmer's grain fields.	Decentralized	Yes
Västanfjärd	Kemiö Archipelago	rural island community with a pilot project to evaluate the performance of different individual onsite sanitation systems with an aim to recycle nutrients	Individual sites using a variety of systems and include urine diversion and greywater treatment. Decentralized urine collection and reuse as fertilizer to local farmer's energy crop fields.	Onsite	Yes
Merimasku Saaristolaiskylä (Merimasku Archipelago Village)	Turku Archipelago	Earlier pilot project in a new neighborhood zoned for dry toilets. The neighborhood was rezoned in 2005 and connected to the nearby wastewater treatment plant	Separate onsite systems. Dry toilet with greywater treatment. All but 2 systems diverted urine. Onsite urine reuse varied according to site.	Onsite	Yes

RESEARCH METHODOLOGY

Literature review and interviews were used to assess the current situation of wastewater management systems (WMS) in Finland, site selection, and the preliminary stakeholder analysis. The two tools used in the research originate from WUR's global comparative sanitation assessment. Due to the small sample size of sites and of interviews within the sites, the data cannot be seen as statistically representative, but is used to make inferences about the general situation at the sites.

The stakeholder analysis identified the appropriate decision makers and the drivers and barriers analysis brought insight into the reasons behind specific technology choices. Via questionnaire, decision makers rated the importance of certain aspects in three categories (Environmental/Public Health, Financial, and Social/Managerial) to their technology choice decision making process and to list influential legislation.

The in-the-field performance assessment of the various options was based on interviews with householders and sanitation system owners inquiring about system description, household information, and six performance dimensions (a) invisibility and user comfort, b) system robustness, c) public health, d) impact on ecosystem, e) surface and groundwater management, f) user knowledge and training). As many as possible interviews were conducted in the limited time available at each site and therefore the numbers vary from site to site. Information not retrieved from interviews was found via literature review or additional interviews.

The performance analysis includes a cross-site comparison of the five sites, but six potential sanitation choices, as urine-diverting and non urine diverting onsite systems are seen as separate choices. Technical performance is looked at in terms of public health risk and environmental impact, while practical performance covers user-comfort, operations and maintenance requirements and costs. Public health risk is assessed based on observations, interviews, and effluent test reports. The environmental impact analysis is based on the calculation of environmental loads of BOD_7, phosphorous and nitrogen in comparison with the values required by the OWSD and in comparison with each other. User comfort was based on ratings of satisfaction, aesthetics and odor production. Operations and maintenance requirements were looked at in terms of whether and how many hours of maintenance was required of householders. Finally, costs were in terms of household investment cost, upfront capital investment and annual operating costs.

RESULTS

STAKEHOLDER ANALYSIS / DRIVERS AND BARRIERS ASSESSMENT

In both Suvisaaristo and Vessö, the municipalities faced financial obstacles to expanding their networks to rural areas. The network construction funding came from water cooperatives, with the support of Regional Environmental Centers (RECs). In both onsite cases, the municipalities actively promoted the dry toilet projects from the start. Västanfjärd's project also involved the Local Agenda 21 group and volunteer households throughout the project life, while in Merimasku, the municipality merely set the zoning requirements. Overall, the decision makers were mostly the system owners, though at some sites, other actors, such as the municipality or architect, heavily influenced the decision making process.

If the projects were implemented now, all of the decentralized and onsite systems would fall under the requirements of the OWSD. According to the Drivers and Barriers assessment, the aspects that were on average considered important in the decisionmaking process were *protection of surface or sea water* and *groundwater, positive feeling about environmental behavior,* and *taking personal responsibility for household water management systems* (water saving, emissions reduction, etc.). *Recycling of nutrients, water saving, quality of neighborhood landscaping, design costs, operating expenditures, fear of either smell* or *performance problems, positive public relations* (PR) were considered only moderately important or only important to some decision makers.

PERFORMANCE

In this research, public health risk analysis was based on the public's level of and need for access to the sanitation system, the pathogen levels in the effluent, and the location of discharge. All sites show a chance for householders to come into contact with the wastewater on their property. However, with onsite systems, householders need to access these systems for maintenance, in contrast with the networked systems where maintenance is performed by a third party. With both onsite and decentralized source-separating systems, householders reported occasionally having to remove faeces from the urine diverting bowl. The level of risk in the onsite systems further depends on the wastewater fraction and the point in the treatment process at which the householder has contact with it. Some onsite dry toilet systems required householder contact early on in the treatment process prior to the actual composting process. In regards to effluent pathogen levels, data was unavailable at the decentralized level. However, in the centralized site and all of the onsite systems, except the greywater sites, average pathogen levels in effluent exceeded the maximum values (<10^3 units/100 ml) considered acceptable for unrestricted irrigation by the WHO guidelines. In all the cases, except for Suvisaaristo where discharge is at sea, effluent is discharged near their properties into open ditches, ponds or near the shore.

In regards to environmental impact, all the systems met the OWSD's effluent load requirements except for the onsite mixed wastewater treatment system, which had excessive phosphorous loading. One onsite greywater system cluster performed comparable to the decentralized and centralized networks (in all loading categories), while both of the greywater systems had the lowest nitrogen loadings. Both SBR systems' performance exceeded the generally accepted levels of treatment for biological-chemical treatment plants. While the source-separating systems treated wastewater fractions at higher efficiency levels at the onsite level, this is not reflected at the decentralized level.

Table 2. Treatment performance cross-site comparison.

Site		average # of people / hh	Daily water consumption	BOD7 mg/L	P mg/L	N mg/L	Total BOD load	Permissible BOD load	Total P load	Permissible P load	Total N load	Permissible N load
		#	L/day/person	mg/L			g/cap/day					
Suvisaaristo - mixed ww treatment	Centralized	3.5	82	8	0.4	14.0	0.66	5.0	0.03	0.33	1.2	8.4
Vesso average - mixed ww treatment	SBR	2.6	110	4	1.45	29.9	0.45	5.0	0.16	0.33	3.3	8.4
Bromarv average- mixed ww treatment with UD	SBR Urine diversion	2	96	5	0.8	49.0	0.52	5.0	0.08	0.33	4.7	8.4
Merimasku average- GW with some excess BW liquids	ST + SF	2.75	61	31	4.2	9.9	1.88	5.0	0.25	0.33	0.6	8.4
Vastanfjard average- GW treatment	ST + SF	3	93	7	1.42	9.1	0.65	5.0	0.13	0.33	0.9	8.4
Vastanfjard average- mixed ww treatment	ST + reedbedfilter/ ST + SF	3	107	14	6.88	26.6	1.47	5.0	0.74	0.33	2.8	8.4

ST=septic tank, SF=soil filter, GW=greywater, BW=blackwater, WW=wastewater, UD= urine diversion

For the practical performance assessment, the maintenance and operations requirements for householders depended on whether or not the sites were connected to a (-de)centralized network. All of the rural wastewater sanitation projects involved logistics and presented a need for a single entity to coordinate the process train. In all cases, except for Merimasku, a coordinating party ensured households' understanding of their sanitation systems, and organized maintenance or logistics of the process train. Maintenance at the onsite level is the responsibility of the householder and does not require skilled professionals. The networked systems were managed by a knowledgeable employee within the larger organization. The frequency of and the time spent by householders on maintenance depended on the type of onsite system and the existence of problems with the systems. The number of hours spent on maintenance varied between 4 and 22 hours per household annually, and the averages not only varied from area to area, but system to system.

Table 3. Operations and maintenance – cross-site comparison.

Aspect		Suvisaaristo	Vesso	Bromarv	Vastanfjard UD	Vastanfjard Non UD	Vastanfjard all	Merimasku UD	Merimasku Non UD	Merimasku average all		Average Conventional	Average Non-Conventional		Centralized	Average Decentralized	Average Onsite		Decentralizd UD	Onsite UD	Decentralized NUD	Average Onsite NUD	Average NUD	Average UD
Households & adaptations	yes/no	50% yes, 50% no	no	no	yes	yes	yes	yes	yes	yes		75% no	33% no		50% yes, 50% no	100% no	100% yes		no	yes	no	yes	mixed	mixed
Household maintenance	yes/no	no	no	no	yes	yes	yes	yes	yes	yes		100% no	33% no		100% no	100% no	100% yes		no	yes	no	yes	mixed	mixed
maintenance hrs	hours/year	0	0	0	9	10	10	22	5	11		0	5		0	0	10		0	12	0	7	1	5

The user-comfort analysis is based on household ratings, where a difference of two or more points in the rating system has been interpreted as a considerable difference. User comfort was measured by a rating of user-satisfaction, aesthetics, and odor production from their sanitation system. All sites showed high satisfaction ratings and low odor production ratings. All sites, except for Bromarv, were considered to aesthetically fit in the surrounding landscape. Bromarv's moderate rating can be explained by the unfinished landscaping situation at the time of the survey.

Table 4. Invisibility and user comfort – cross-site comparison.

Aspect		Suvisaaristo	Vesso	Bromarv	Vastanfjard UD	Vastanfjard Non UD	Vastanfjard all	Merimasku UD	Merimasku Non UD	Merimasku average all	Average Conventional	Average Non Conventional	Centralized	Average Decentralized	Average Onsite	Decentralizd UD	Onsite UD	Decentralized NUD	Average Onsite NUD	Average NUD	Average UD
Satisfaction	4=very satisfied	4	4***	4	3	3***	3	3	3	3	4	3	4	4	3	4	3	4	3	4	3
odor production	4=strong odor production	0	0***	1	1	2***	1	3	0	2	0	1	0	0	1	1	1	0	1	0	1
aesthetics	4= not fitting with the surrounding landscape	0	1	2***	1	1	1	0	1	0	1	1	0	1	1	2	1	1	1	1	1

*** not rated, but estimated based on comments

Costs were analyzed according to the general investment costs per household, household investment in the sanitation system, and annual operating costs. For the decentralized systems, overall project costs were unavailable and the cost covers the costs of the treatment plant, but not construction or piping. Average estimated up front capital costs range from 3077 to 8017 € and the two highest cost choices were the non-urine diverting onsite systems in Västanfäjrd and the connection to the centralized network. The average costs of the onsite systems range from 4303 to 8017 €. A shared soil filter within the Merimasku urine diverting category was a reason for its low average cost. Categorically, the centralized system costs are the highest and the decentralized are lowest, which is affected by the undervalued costs of the decentralized system. The conventional and non-conventional technology costs are roughly 1000 € apart. If the undervaluing of the decentralized system costs was corrected for, the range of up front capital costs would be smaller.

The cost actually paid per household, however, differed considerably (ranging from 0 to 9042 €) depending on how the system costs are passed on to the user and whether subsidies exist. Onsite system owners, or households, are responsible for their system and installation costs, though Västanfjärd households received subsidies. Suvisaaristo and Vessö householders pay water cooperative membership and connection fees, while householders in Bromarv do not specifically pay for wastewater costs. Since Bromarv and Västanfjärd skew the categorical averages, it might be more fair to exclude Bromarv and then to compare the *household investment cost* of the other networked systems with the *upfront capital investment* of the householders of the onsite systems. As such, the costs of connecting to the centralized system (9052 €) are still highest, but onsite (5743 €) and decentralized (5005 €) are comparable.

Annual operating costs were similar at all levels, with the lowest cost average site cost at 131 € in Västanfjärd and the highest at 394 € in Merimasku, both of which are onsite system areas. Merimasku's costs were affected by the system problems and the short system life spans. There was no real difference between the costs categorically.

Table 5. Cost comparison.

Description		SS	Vesso	Bromarv	Vst UD	Vst NUD	Vst	MM UD	MM NUD	MM	C	DC	OS	Ave UD	Ave NUD	Conv	Non Conv
What is the up-front capital investment per household in EURO of the process train?	**€/hh**	**7059**	**4762**	**3077**	**5581**	**8017**	**6393**	**4303**	**5882**	**5092**	**7059**	**3920**	**5743**	**4320**	**6221**	**5910**	**4854**
How much did the householder invest in the sanitation system? TOTAL	**€/hh**	**9042**	**5005**	**0**	**2790**	**4009**	**3196**	**4303**	**5882**	**5092**	**9042**	**2503**	**4144**	**2364**	**4965**	**7023**	**2763**
Household connection fee	€	2101	3000								2101	**3000**			**3000**	**2550**	
Membership fee for water coop	€	100	505	n/a	n/a	n/a					100	**505**			**505**	**303**	
Household investment in outsourced labor/installation costs	€	6841	1500	0							6841	**750**		**0**	**1500**	**4171**	**0**
Household investment urine tank and toilets *	€/hh			0	1273	769	1105	924	2521	1723		**0**	**1414**	**732**	**1645**		**942**
Household investment in soil filter	€			0	870	524	697	2521	3361	2941		**0**	**1819**	**1130**	**1942**		**1213**
Other cost	€				1083	2717	1627	1714	0	857			**1242**	**1398**	**1358**		**1242**
What is the estimated annual per household operating cost in EURO of the process train?*	**€**	**224**	**330**	**230**	**131**	**131**	**131**	**369**	**420**	**394**	**224**	**280**	**263**	**243**	**294**	**277**	**252**
LOKA vehicle costs	€/hh	0	22	10	131	131	131	88	0	44	0	**16**	**88**	**76**	**51**	**11**	**62**
Annual administrative costs	€	109	110	0	0	0	0				109	**55**	**0**	**0**	**55**	**110**	**0**
Maintenance costs	€				**	**		281	420	351			**351**	**281**	**420**		**351**
wastewater charges	€	115	220	220	0	0	0				115	**220**	**0**	**110**	**110**	**168**	**110**

UD=urine diverting, NUD=Non urine diverting, ST=septic tank, SF=soil filter, GW=greywater, SS=suvisaaristo, Vst=Västanfjärd, MM=Merimasku, C=centralized, DC=Decentralized, OS=Onsite
* paid by system owner, ** do not have basis for estimation, but costs do exist

DISCUSSION AND CONCLUSIONS

According to the drivers and barriers assessment, the goal of recycling nutrients from wastewater only played a role in the decision making process at some sites. Despite theoretical benefits of source separation, evidence of improved treatment efficiency was limited to onsite systems. However, further DESAR research via experimental sites regarding possible benefits at decentralized level is recommended. This research concludes that decentralized options can offer many of the benefits associated with centralized systems, at a potentially lower cost to system users and owners. While centralized systems ensure high environmental protection through systematized monitoring systems and appropriate management, all of the categories, except for the onsite systems treating mixed wastewaters, met the required OWSD loading standards. Moreover, the **environmental impact** of decentralized systems and greywater onsite systems were comparable and sometimes even lower than that of centralized systems. Although new technologies available at the decentralized level offer very high treatment levels, it should be noted that long term performance data of such systems is not available. Furthermore, the performance analysis does not account for the influent nutrient loads.

In terms of **public health risk**, the connection to a more distant centralized system in a rural area has more risk than a connection to a centralized system in an urban area due to the possible requirement of additional onsite infrastructure. However, in general, the public health risks for source separated systems are higher due to more householder contact with untreated discharges. Future research should include a quantitative analysis of the whole process train (from the infrastructure of the user, i.e. toilets to discharge point).

Although it is expected that **user comfort and invisibility** would increase with the level of centralization of sanitation networks, this was not supported by the results. Although maintenance tasks and the annual number of maintenance hours was much higher for the onsite systems than (-de)centralized systems, householder ratings of satisfaction, odor production and aesthetics showed no differences.

Annual **costs** per household were more comparable between sites than system costs. For the investment costs, onsite system costs varied based on the individual system and installation details, while the costs of connection to (-de)centralized networks are affected by distance between households and the network and households to each other and the number of connections, etc. The decentralized systems showed potential for low costs compared to onsite and centralized choices, especially when the treatment plants were used at maximum capacity (maximum number of connections). Also, onsite sanitation systems can further reduce costs through the sharing of components, like soil filters, with other households in close proximity to each other.

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