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Wastewater disposal in rural areas

Matthias Barjenbruch

TU Berlin, Department of Urban Water Management, Sek. TIB 1 B16, Gustav-Meyer-Allee 25, 13355 Berlin, Germany
Tel. +49 30/314-72247; Fax: +49 30/314-72248; email: matthias.barjenbruch@tu-berlin.de

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ABSTRACT

In rural areas, the quality of the water bodies will continue to be influenced by the purification performances of small and smaller wastewater treatment plants (WWTPs). In this paper, the different methods of wastewater discharge and treatment currently available for rural areas were presented. Today, both technical and natural methods achieve purification results which are equivalent to, if less stable than those of larger technical pants, provided that dimensioning, design, and operation are optimally cared for. The general question will be to decide for a centralized wastewater system or for local, on-site solution installing small treatment plants. Important criteria for this decision as the distance between the houses and also crucial dimensioning parameters like the amount of wastewater will be given within the report. Several wastewater treatment technologies will be explained and also results from the SBR-System, which are applied in Germany special in smaller communities, are discussed. The evaluation of monitoring values showed that on average the required effluent qualities could be obtained. But still one has to consider that there are technical and economic limits of the degree to which WWTPs can be cared for in rural areas. For on-site treatment the main reasons is the organization of a good operation, maintenance and surveillance.

Keywords: Wastewater discharge systems; Centralized or on-site treatment; Rural areas; Treatment technologies; Effluent values, Organisation of surveillance

1. Introduction

For more than 100 years, central wastewater disposal with gravity sewer systems or with conveyance by pumps to wastewater treatment plants has stood the test of time in urban settlements, particularly for hygienic and economic reasons. Still, these systems are subject to continuous modification.

New developments have been advanced particularly with regard to the separation of part-streams and to rainwater infiltration in order to monitor and control the discharge situation. In rural areas, however, differing frame conditions necessitated special solutions at very early stages in the development of wastewater treatment. Such conditions are, among others (cf. [1]):

- Low settlement concentration of up to 25 PE/ha of settlement area
- Large settlement lots due to loose open development, single homesteads
- Settlements with scattered buildings
- Small villages and districts far apart from each other
- Low ratios of covered surface (up to 20% of the settlement areas)
- Low implementation of sewage and treatment systems
- Rainwater discharge into nearby waters
- High ratio of areas under environmental protection
- Seasonal variation of the wastewater amounts due to tourism

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2. Central wastewater disposal or on-site-treatement

There are no standard definitions of "central" and "semi-centralized" systems. Semi-centralized must be differentiated to an on-site treatment. In this paper, the terms are used as follows:

Central wastewater disposal:

The wastewater is collected within a larger settlement area and mostly treated at some distance from where it was produced. A disposal network with one central WWTP is established.

Semi-centralized wastewater disposal:

The wastewater of single houses is locally treated on site; the connection of neighbouring houses is possible, too. On the other hand, the term "local" is also used for the treatment of wastewater from single districts or single villages which are situated near the areas where the wastewater is produced.

On site-treatment or local wastewater disposal systems in residential areas with small WWTPs directly on the sites (<50 PE or <8 m^3/day) can provide a sustainable solution especially if public sewage systems would lead to unacceptably high costs. Choosing local solutions you have to regard the hygienic conditions, monitoring and maintenance problems and the sludge disposal.

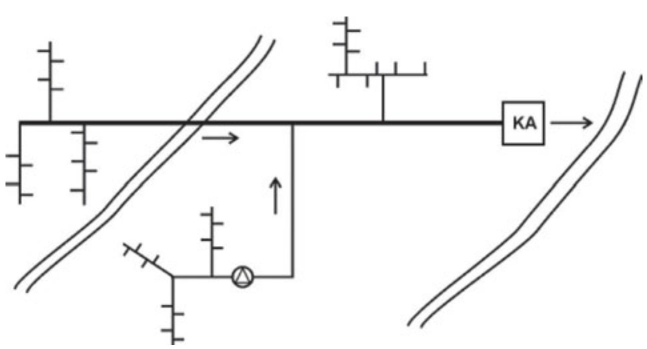

Fig. 1. Central wastewater disposal [2].

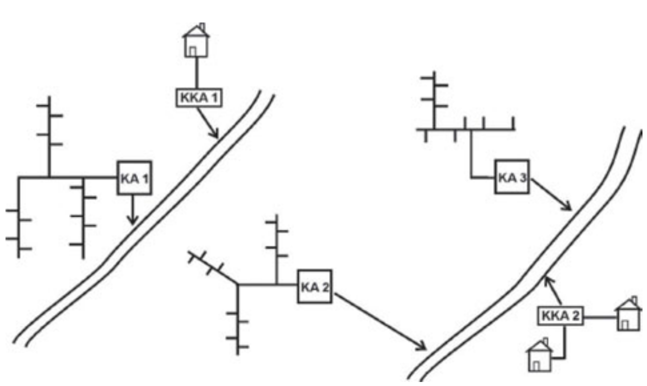

Fig. 2. Semi-centralized wastewater disposal [2].

If the authorities have to decide whether for a given disposal area a central or local solution should be developed, they have to check first if the overall situation (protection areas, receiving waters, insufficient gradients, lack of infiltration opportunities) generally allows for a local solution.

On the other hand the costs of both variants have to be compared on the same planning level. The costs depend among other factors also from the distance between the houses and between the village and a potential site of the WWTP. A general length of a sewer system can not be given because it depends on the local conditions. For centralized solutions about 70% of the costs are caused by the sewer system and 30% by the WWTP. Constructional cost of a gravity sewer, e.g. DN 200 is about 300 €/m (based on German prices).

The yearly costs of technical semi-centralized WTP vary between 40 and 150 €/(PE · annum) [3]. The costs of wetlands as an on-site treatment for four persons are about 150 €/(PE · annum)[4].

3. Options of wastewater disposal

Wastewater can be discharged in a number of ways. However, the gravity sewer systems which are most frequently used in urban areas quickly reach their limits in rural areas:

- *Gravity sewer system* Classical solution with flow provided by gravity, separated or combined system; if possible, rainwater is infiltrated locally or discharged separately.
- *Pit* combined with truck Wastewater is stored, and then extracted and removed be a suction pump vehicle.
- *Vacuum drainage system* Wastewater is collected in small pits; when the pit is full, a valve is opened and the wastewater sucked by low pressure of 60–70 kPa (max. 10 WS) to a central vacuum station and disposed from there.
- *Pressure drainage system* Many smaller pumping stations which discharge the wastewater of single buildings or smaller groups of buildings via a common network of pressure pipes.
- *FLAT drainage system* Coarse substance settle in a local septic tank, wastewater without particles can then be conveyed in a pressure pipe with a smaller diameter.
- *Modern sanitation concepts* (ECOSAN), where urine and faeces are immediately separated in suitable toilets. The urine can be used as fertilizer; the faeces can be composted or used for the production of biogas.

For all methods mentioned above, the economic efficiency must be examined for the single cases by comparing the variants.

4. German effluent requirements

According to the German Wastewater Directive, WWTPs with a connection size below 5,000 PE and also local small WWTPs have to fulfill only minimum requirements for the organic pollutant parameters BOD_5 and COD:

- Size 1–60 kg BOD_5 (raw) < 1,000 PE
  COD < 150 mg/l BOD_5 < 40 mg/l
- Size 2–300 kg BOD_5 (raw) < 5,000 PE
  COD < 110 mg/l BOD_5 < 25 mg/l

In Germany, the nutrient parameters nitrogen and phosphorous are not uniformly limited for plants of this category. However, more extensive requirements may come from the water authorities in order to achieve or sustain the target quality of a given water body (the principle of the consideration of immision values).

5. Wastewater condition

5.1. Wastewater production

According to German Standards (e.g. [5]) one has to calculate with a daily wastewater production of 150 l/(PE · day). This value contains local small industries such as pubs and butcher's shops. For sewer system additionally infiltration water with a value of 25% to 100% must be added.

In a survey of different operators of WWTPs, the average specific wastewater production for rural areas in Mecklenburg-Western Pomerania was determined as approximately 110 l/(PE · day) at a range of 65–245 l/(PE · day). Local conditions can vary dramatically in relation to the respective settlement structures. Actually the specific wastewater production in rural areas amounts to only 80 l/(PE · day) in some parts.

5.2. Wastewater composition

If there are no measured data specific pollutant loads are used for the dimensioning of WWTPs in rural areas. For the German wastewater conditions, one assumes the following load values: 60 g BOD_5/(PE · day), 120 g COD/(PE · day), 11 g N/(/PE · day) and 1,8 g P/(PE · day). Table 1 summarizes influent concentrations resulting in relation to the wastewater amount. The top line represents the "European standard wastewater". The other values represent measured values which occur due to the different degrees of dilution caused by rainwater, water from external sources, or user behaviour.

6. Wastewater treatment

The allocation of the wastewater treatment methods is not unequivocally defined in this area. In this paper, it is differentiated between:

- Local small WWTPs <50 PE or <8 m^3/day
- Smaller WWTPs 50–5,000 PE

In Germany, 71% of all wastewater treatments plants are run by municipalities <5,000 inhabitants, but the other 29% of the plants deal with 94% of the wastewater load. This means that particularly for the rural areas many separate operation points must be serviced. These considerations show that the selection of the method and the safe operation of the WTPS of this size are of major importance. Following treatment technologies can be applied in rural areas as well as small WWTPs or smaller WWTPs:

Natural methods:

- Reed beds (vertical or horizontal flow)
- Settling ponds (only mechanical effect)
- Unaerated wastewater lagoons (up to ~1,000 PE)

Table 1
Comparison of different concentrations in the raw wastewater [6]

Parameter (mg/l)	BOD_5	COD	SS	N	P
EN 12566-3 (2003)	150–500	300–1.000	200–700	22–80	5–20
Influent test field (average value)	521	913	255	76[b]	13
Variation range	180–760	531–1.336	82–558	51–111[b]	9–25
Analysis DWA Nord-Ost (2002)	533	1.082	n.d.	104	18
Bavaria DWA (2004)	306	560	n.d.	58	9.8
Raw wastewater according to DWA A 131[a]	400	800	466	73	12

[a]Concentration calculated with 150 l/(PE · day).
[b]Only NH_4–N.
n.d., not determined.

- Aerated wastewater lagoons (up to ~5,000 PE)
- Wastewater lagoons with technical intermediate stage (trickling or submerged filter)

Technical wastewater treatment method

- Mechanical—biological wastewater treatment plant in separate design
- Mechanical—biological wastewater treatment plant (compact design)
- Wastewater treatment plants with additional or innovative technologies (compact design, container-technology)

The mechanical stage should be equipped with a fine screen or sieve unit for the separation of coarse material. As inexpensive casing, ready-made garages or wood constructions are suitable. The biological stage can be realized by the following operation methods:

- Activation methods (SBR plants, oxidation ditches, compact plants, membrane bioreactors)
- Biofilm reactors like trickling filters, rotating disc, fixed bed reactors (aerated), moving bed methods

Apart from the calculation of the economic efficiency, the following aspects must be considered for the selection of the suitable operation method [1]:

- Efficiency and stability of the purification methods and sustained observance of the required monitoring values
- Robustness and simplicity of the process technology
- Easy maintenance and accessibility to facilitate the required operation and the pre-scribed measurements for the plant's self-monitoring
- Safety of sludge disposal and removal of the other residual substances (screenings and grit chamber trappings)
- Options for the gradual extension of the plant

Especially for small German communities the Sequencing Batch Reactors (SBR method), which are fed discontinuously, have recently become one of the most suitable technology. Currently, far more than 200 plants for municipal and industrial applications are operating in Germany. The process stages—feeding, treatment (stirring and aeration), sedimentation of the sludge, cleaned water decanting and excess sludge extraction—are performed in one tank (Fig. 3). The advantage is that a secondary clarifier with sludge recirculation is not necessary. Still, the total volume which must be constructed is higher (additional storage space).

Table 2 shows the statistical evaluation of the effluent values. Compared to the values of conventional plants, the plants analysed here achieved better values.

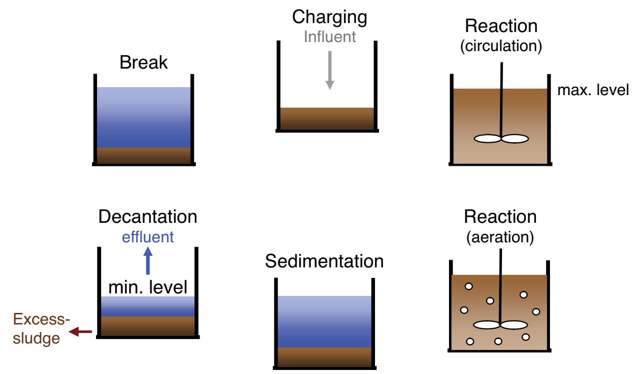

Fig. 3. Cycle and part process of the SBR method [7].

Table 2
Effluent values from the official monitoring of SBR plants (six plants) [7]

In (mg/l)	BOD_5	COD	NH_4–N	Total $N_{anorg.}$	Total *P*
Number of measurements	31	31	30	30	31
Average	19	69	14.3	21.3	4.5
Min	3	15	0.01	0.01	0.04
Max	144	294	120	120.0	35.9

7. Application and purification performances of small WWTPs

The suitable application areas for small WWTPs depends in particular on the simplicity of the operation method, the possible dynamics of the wastewater production, and the pollutant load (seasons; vacations), and partly on the area demand. For instance, activation plants have considerable operation problems with small connection sizes especially after holiday breaks.

Barjenbruch and Al Jiroudi ran comparative analyses on a test field, using six different plant types [5]. The best effluent values in the first analysis year were achieved with the reed bed with vertical flow (Ø 70 mg COD/l). One important restriction, however, is that the plant was periodically out of order in winter. The reed bed with horizontal flow (Ø 78 mg COD/l) and the submerged bed (Ø 75 mg COD/l) achieved continuously good purification degrees, followed by the SBR plant (Ø 79 mg COD/l), which worked in a very stable way after the program had been optimized shows the minimum, maximum, and average COD effluent values over the entire test period and the relative time ratios without operation disturbances and without exceeding of the monitoring values. High availability

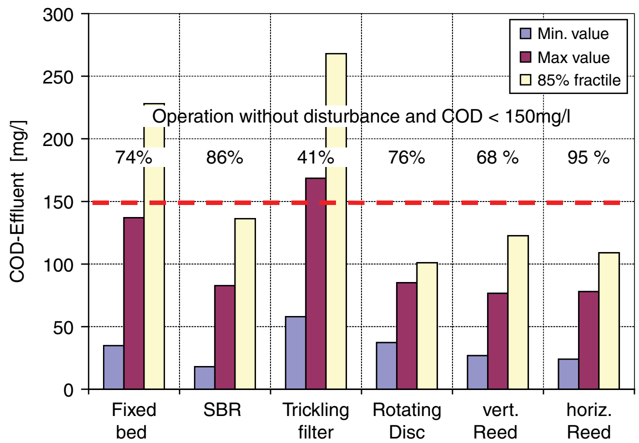

Fig. 4. COD effluent values and disturbance-free operation over the test period [6].

degrees were achieved by the reed bed with horizontal flow (95%) and, with small reservations, also the SBR plant (86%).

8. Surveillance and its organisation

Maintenance and surveillance are crucial factors for a proper operation of the SWWTPs. In Germany the respective authority is responsible for the surveillance of the performance of SWWTPs. There are several legal options:

(a) Self-Surveillance-Model: The owner of the SWTP is obliged to send the report, containing the effluent values, to the respective authority. If the report indicate a failure in operation, the authority intervenes. Furthermore, the authority can examine grab samples anytime.
(b) Expert-Model: An independent expert carries out the surveillance. He or she can be chosen from a range of experts or every region has its proper expert. This way also the work of the maintenance-companies is supervised.
(c) Municipal-Model: The municipal authority surveys the SWWTPs directly. A disadvantage appears in the case that the municipal authority operates the same treatment plant.

The surveillance model should ensure the safe operation of the SWWTPs and demand as little effort as possible.

9. Conclusions

Under the special conditions of rural areas different possibilities for the wastewater disposal can be applied. Under the aspects of costs for installation and operation as well as regarding the environmental, water management and social influences you have to decide between (semi-)centralized or on-site solutions. Also an operational model must be integrated. For both variants practical experiences are available. But no generalisation is possible, a local application always needs an adjusted solution.

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