

## Research Paper

# Utilization rates, water demand and wastewater characteristics of a shared sanitation facility in North Namibia

K. Müller, P. Cornel and A. Nashilongo

### ABSTRACT

Shared sanitation facilities are often the only feasible option for sanitation provision in informal settlements. When implementing infrastructure for wastewater collection and treatment, information regarding quantities and constituent loadings is required. Up to now, such data are not available for shared sanitation. In order to provide this information, this study focuses on wastewater characteristics of a shared sanitation facility in North Namibia. The input data used for planning are compared with monitoring data. This includes utilization rates, water demand, loads and concentrations of total chemical oxygen demand, total nitrogen, total phosphorus and total dissolved solids. During the survey period, two different tariff levels were tested. Their effect on utilization rates and water demand is outlined. The results obtained from this study are particularly valuable for better planning of shared sanitation facilities, and subsequent wastewater transport, treatment and reuse infrastructures. Future studies should include further aspects and influencing factors such as population density, available income, or the influence of competing facilities.

**Key words** | communal sanitation, informal settlements, shared sanitation, toilet facilities, wastewater characteristics, water demand

**K. Müller**

**P. Cornel** (corresponding author)  
Technische Universität Darmstadt, Institute IWAR,  
Franziska-Braun-Str. 7,  
Darmstadt 64287,  
Germany  
E-mail: [p.cornel@iwar.tu-darmstadt.de](mailto:p.cornel@iwar.tu-darmstadt.de)

**A. Nashilongo**

Outapi Town Council,  
Outapi/Tsandil Main Road,  
Outapi,  
Namibia

### INTRODUCTION

Shared sanitation facilities are facilities that provide water and sanitation services to several households (World Health Organization [WHO] & United Nations Children's Fund [UNICEF] 2013). In 1990, sharing was common practice for 160 million people or 7% of the world's urban population and, in 2015, this number had more than doubled, to 394 million people or 10% of the urban population (UNICEF & WHO 2015). Shared sanitation is widely practiced, particularly in informal settlements (Schouten & Mathenge 2010) and very often constitutes the only feasible option for provision of water and sanitation services (Mara 2005). Exley *et al.* (2015) conclude that 'without reconsidering shared sanitation, the Millennium Development Goals, and future targets, are unlikely to be met'.

Sanitation provision has to go beyond collection of wastewater and must include transport, treatment, and discharge or reuse of treated water and sludge (Mehta & Mehta 2013). When planning wastewater collection, transport and treatment facilities, information about wastewater quantities, flow rates, and constituent loadings is necessary (Tchobanoglous *et al.* 2004).

There are sufficient data that can be used for estimating the daily per capita water demand and loads of common wastewater constituents. Together with the projected number of future users or households that are going to be included in the sanitation system, total water quantities, loads and concentrations can be calculated and serve as a basis for detailed planning.

However, when implementing shared sanitation, the future number of users and the ultimate use of one facility are less definite as some individuals might use it more often or for other purposes than others. Hence, water demand and constituent loadings will certainly differ from typical values for individual sanitation facilities.

Examples of shared sanitation from Kenya report mean utilization rates of 416 (Schouten & Mathenge 2010) and 600 users per day (Lüthi *et al.* 2011). Biran *et al.* (2011) report about 482 users per day for facilities in India. For an example in Madagascar, 220 'defecations per day' are given (Norman 2011). No long-term monitoring data has been published or data that could explain variations or trends in utilization rates or influencing factors (e.g., tariffs, population density).

Water quantity data is only available for four facilities in South Africa with a water use ranging from 4.4 to 12.0 m<sup>3</sup>/d per facility (Crous *et al.* 2013). Data on loads or concentrations of wastewater from shared sanitation facilities could not be found.

Altogether, research mainly provides knowledge on the general feasibility, institutional and sociological topics and appropriateness of shared sanitation facilities (e.g., Hobson 2000; Burra *et al.* 2003; Cousins 2004; WaterAid India 2008; Biran & Jenkins 2010; Norman 2011; Roma & Jeffrey 2011; Water and Sanitation for the Urban Poor [WSUP] 2011; United States Agency for International Development [USAID] & WSUP 2013; Mazeau *et al.* 2014; Tumwebaze & Mosler 2014) but not on the characteristics of the untreated wastewater. Shared sanitation facilities 'are proving highly effective, because they concentrate usage in one place and so make sewer connections, management and operation financially viable' (Eales 2008). For purposeful planning, information on expectable wastewater quantities, concentrations and loads is indispensable.

Thus, this work focuses on planning and implementation of a larger shared sanitation facility as a part of a project on sanitation and water reuse in North Namibia. The paper starts with a short project description and how data collection was carried out. Planning data and monitored values of utilization rates and wastewater characteristics are compared. Possible reasons for differences are discussed and the effect of increasing tariffs on utilization rates, water quantities, and specific water demand is explored. Other important aspects such as capital costs,

operation and maintenance costs, management strategies, wastewater treatment and reuse options go beyond the scope of this work and are addressed in other documents published on the basis of the described project (Deffner & Mazambani 2010; Deffner *et al.* 2012; Deffner & Böff 2012; Deffner & Kluge 2013; Liehr *et al.* 2016a, 2016b).

## MATERIALS AND METHODS

### Study area and project description

This study was carried out in the city of Outapi in North Namibia that has a total population of 6,437 persons (Namibia Statistics Agency [NSA] 2011). The population density is approximately 21.5 persons/ha (based on the approximate town area of 3 km<sup>2</sup>, estimated using Google Earth Version 7.1.2.2041 (2013)).

Together with local stakeholders, Outapi has been chosen as the location for implementing a concept for sanitation and water reuse (Deffner & Mazambani 2010; Deffner & Kluge 2013). Project partners for the implementation are the Institute for Social-Ecological Research (ISOE, Frankfurt, Germany), the Technische Universität Darmstadt (TUDa, Darmstadt, Germany), Bilfinger Water Technologies (BWT, Hanau, Germany), the Outapi Town Council (OTC, Outapi, Namibia), the Desert Research Foundation of Namibia (DRFN, Windhoek, Namibia), and the Ministry of Agriculture, Water and Forestry (Windhoek, Namibia). The project is funded by the German Federal Ministry of Education and Research.

The project implements three types of sanitation facilities in three differently developed areas (Figure 1): (1) 30 smaller shared facilities for up to 4 households each, (2) individual connection of 47 households, and (3) one larger shared facility for up to 250 persons from the community and a nearby market place. The wastewater is transported by vacuum sewers to a wastewater treatment plant where it undergoes a combined sedimentation/anaerobic pretreatment, aerobic treatment, secondary clarification, microscreening, and ultraviolet disinfection before it is used for irrigation of vegetables grown for human consumption. More details are provided in Müller & Cornel (2016).



**Figure 1** | Regional context of the study area and overview of the location of the 30 smaller shared sanitation facilities (1), the 47 individually connected households (2), the larger shared sanitation facility (3), the water reuse plant and storage pond (4), and the irrigation sites (5 and 6), (sources: Kluge *et al.* (2008); ISOE (2010); Google Earth Version 7.1.2.2041 (2013), modified).

## Water quantities

Water quantities of the shared sanitation facility were measured with domestic multi-jet water meters (MNK, Zenner and Model M, Arad) between May 2013 and September 2015. The cumulative water demand was recorded from the water meters by the project's laboratory assistant, usually at 8:00 am during weekdays (sometimes during weekends).

## Daily utilization rates

Billing was carried out on a pay-per-use basis, via a voucher system. Vouchers were sold at the OTC and at the sanitation facility. They were collected by the facility's caretakers and allowed the use of all the provided services during one visit.

The vouchers were used to determine the utilization rates from May 2013 to July 2014. They were reclaimed from the caretakers by the laboratory assistant and counted

later. From August 2014 to September 2015, utilization rates were determined from tally sheets. These were filled out daily by the caretakers at the sanitation facility and collected from time to time by the laboratory assistant. To ensure that the determined utilization rates do not differ between the two data collection methods (voucher counts and tally sheets), both were applied in parallel from May 2014 to July 2014. There were no significant differences between the two methods.

## Water quality

Concentrations of total chemical oxygen demand (TCOD), total nitrogen (TN), and total phosphorus (TP) were measured in flow-proportional, 10-hour mixed wastewater samples (according to the opening hours of the sanitation facility) between May 2013 and October 2013. In tap water these parameters were determined in three grab samples. Hach Lange cuvette tests were used for the

analyses (LCK 314, LCK 414, LCK 138, LCK 338, LCK 348, LCK 350, for working procedures see [www.hach.com](http://www.hach.com)). The concentrations were determined in homogenized wastewater samples (double determination, homogenizer: T 25 digital Ultra-Turrax, IKA).

The tap water samples were analyzed without prior treatment (double determination). The measured TCOD, TN, and TP concentrations in the tap water samples were below the detection limit. Thus, when determining the loads per usage, it is assumed that these concentrations in tap water are 'zero'. The TDS concentration in tap water is 40.2 ( $\pm 2.7$ ) mg/L ( $n = 3$ ) and this was deducted from the total load; thus, loads per usage correspond to input during water use.

The determination of total dissolved solids (TDS) in the untreated water was not possible in this case due to rapid clogging of the glass fiber filters (Whatman 934-AH) and the relatively low TDS content in the samples requiring the evaporation of considerable amounts of water to obtain a sufficient quantity of weighable residues. Due to its simpler way of measuring, a surrogate parameter, e.g., the electrical conductivity (EC), is often used instead (Eaton & Franson 2005) and was also used in this study.

The TDS/EC conversion factor had to be determined. Hence, TDS was measured in the effluent of the wastewater treatment plant due to its better filterability compared to the untreated water. The samples were filtered through glass microfiber filters (Whatman 934-AH, pore size: 1.5  $\mu$ m retention) and dried at 105 °C until the samples reached constant weight. TDS was determined four times. For each determination, the mean value of multiple measurements (2 or 3) was calculated. For the measurements, sample volumes between 8 L and 19 L were evaporated. Together with the EC measured in these samples (EC meter: Multi 1970i, electrode: TetraCon 325, WTW), a conversion factor of 0.62 ( $\pm 0.03$ ) (mg  $\times$  cm)/(L  $\times$   $\mu$ S) was determined. For instance, 2.78 g solids were obtained from evaporation of 8.52 L sample volume with an average EC of 526  $\mu$ S/cm. Thus, the conversion factor for this sample is 2.78 g  $\times$  1,000 mg/g  $\div$  8.52 L  $\div$  526  $\mu$ S/cm = 0.62 (mg  $\times$  cm)/(L  $\times$   $\mu$ S).

The EC was measured during weekdays in grab samples from the untreated wastewater. The conversion factor was used to calculate TDS in the raw wastewater.

## RESULTS AND DISCUSSION

### Planning and implementation

The final design of the shared sanitation facility was selected on the basis of the outcome of several meetings between OTC, DRFN, TUDa, BWT and ISOE, as well as from findings of several community workshops. OTC decided that a facility serving up to 250 residents should be implemented in the chosen area. Assuming a utilization of 3 uses/(user  $\times$  d) (assumption based on discussions with OTC, DRFN and community members), the anticipated utilization rate would be 750 usages/d. The final design was elaborated by a Namibian civil consultant in compliance with the local regulations. It included sections for male and female users with, in total, 14 flush toilets, 15 showers, 24 hand wash basins, 11 sinks for washing laundry and fencing to restrict access.

To design the sewers and wastewater treatment steps, estimations of expected water quantities, concentrations and loads were required. Information related to planning recommendations for comparable facilities was not available among project partners or in the literature. The majority of the future users did not have previous experience with sanitation, in general, and shared sanitation, in particular. Hence, assumptions regarding the future water demand, loads and concentrations had to be made in cooperation with the local experts, OTC and DRFN, based on their experiences and the results of the community workshops.

The future water use was estimated at 60 L/(user  $\times$  d), based on the recommendations given in Gleick (1996) and UN-HABITAT (2003), and the outcome of the community workshops. Von Sperling (2007) reports typical per capita loads for developing countries (TCOD = 100 g/(capita  $\times$  d), TDS = 120 g/(capita  $\times$  d), TN = 8 g/(capita  $\times$  d), TP = 1 g/(capita  $\times$  d)). These values were used for the calculation of future concentrations and total loads contained in the wastewater.

Regarding collection of tariffs, OTC opted for a voucher system. During the project period, two tariffs were tested. Initially, a fee of 0.5 NAD/usage or 0.04 EUR/usage (=tariff 1, May 2013 to August 2014, [www.oanda.com](http://www.oanda.com)) was introduced. In September 2014, the OTC decided to introduce a fee of 2 NAD/usage or 0.13 EUR/usage (=tariff 2, September 2014 to September 2015, [www.oanda.com](http://www.oanda.com)).

**Table 1** | Planned and monitored utilization rates, average water demand per day and specific water demand per usage

Mean	Planned Mean	Monitored: May 2013–Sep 2015			Monitored: May 2013–Aug 2014 (tariff 1)			Monitored: Sep 2014–Sep 2015 (tariff 2)		
		SD	n	Mean	SD	n	Mean	SD	n	
Utilization										
Usages	usages/d	usages/d	usages/d	–	usages/d	usages/d	–	usages/d	usages/d	–
	750	166	72.1	676	208	67.7	289	120	26.9	387
Water demand										
Total	m <sup>3</sup> /d	m <sup>3</sup> /d	m <sup>3</sup> /d	–	m <sup>3</sup> /d	m <sup>3</sup> /d	–	m <sup>3</sup> /d	m <sup>3</sup> /d	–
	15.0	16.7	5.0	387	19.2	4.8	231	14.5	4.4	156
Per usage	L/usage	L/usage	L/usage	–	L/usage	L/usage	–	L/usage	L/usage	–
	20.0	101	36.8	377	92.3	32.5	225	120	30.3	152

SD = standard deviation of the mean, n = number of measurements.

## Monitoring data

### Daily water demand

The mean water demand of the sanitation facility was 16.7 m<sup>3</sup>/d (Table 1). This was only slightly higher than the planned mean water demand of 15.0 m<sup>3</sup>/d. Prior to the introduction of the higher usage fee, the mean water demand was 19.2 m<sup>3</sup>/d (May 2013 to August 2014). Thereafter, the mean water demand decreased to 14.5 m<sup>3</sup>/d (September 2014 to September 2015). Hence, quadrupling the usage fees caused a 24% decline in water demand. The differences are statistically significant at the 1% significance level (Wilcoxon matched-pairs test,  $P$ -value = 0.000).

The water demand of comparable South African shared facilities was 8.2 m<sup>3</sup>/d (Crous *et al.* 2013) and thus lower than the daily water demand in this study. A similarity between the two sites is the large fraction of greywater. In Outapi, 71% of the wastewater is greywater (mainly from showers); in the South African case, this value is 81% (mainly from laundry sinks). Thus, in both examples, greywater constitutes the main wastewater flow.

### Number of usages

During the entire monitoring period, the average utilization rate of the sanitation facility was 166 usages/d (Table 1), ranging from 13 to 554 usages/d. Low values occurred during days with temporary interruption of the local tap water

supply. Before the introduction of the higher usage fee, the average utilization rate was 208 usages/d. Subsequently, it was 120 usages/d. The difference is statistically significant at the 1% significance level (Wilcoxon matched-pairs test,  $P$ -value = 0.000).

This is much less than planned and less than most of the examples mentioned in the introduction. The facility was constructed to provide sanitation services to 250 residents or 750 usages/d. The actual utilization rates represent only 28% (tariff 1) or 16% (tariff 2) of the presumed value. The decrease after introduction of tariff 2 suggests that economic constraints have a major influence. Additionally, a more favorable location for the facility would have been beneficial, because only approximately 50% of the area within a 200 m radius around the facility is occupied by dwellings (Figure 1). Once these areas develop, higher utilization rates are likely.

### Specific water demand

The total water demand per day and the total number of usages per day were used to calculate the water demand per usage. During the entire survey period, on average 101 L were consumed per usage. Following the introduction of the higher usage fee, the specific water use increased from 92.3 L/usage to 120 L/usage. It appears that increasing tariffs led to a more intensive use of the sanitation facility because users tried to use the provided services as much as possible during one visit. The observed differences are

statistically significant at the 1% significance level (Wilcoxon matched-pairs test,  $P$ -value = 0.000).

A water demand level of 60 L/(user × d) and 3 uses/(user × d) would result in a specific water demand of 20 L/usage. The monitored water demand is much higher. This is attributed to the billing on a pay-per-use basis, which leads to a relatively high value for specific water demand, because users combine laundry washing, showering, and toilet use. Control of specific water demand is required to optimize the total water demand. This could be achieved via regular facility inspections and supervision of the users' activities by the caretakers.

### Concentrations and loads

Average concentrations for TCOD, TDS (based on EC), TN, and TP were 579, 377, 38.6 and 8.8 mg/L, respectively (Table 2). This was much lower than expected (−47% to −81%). Average daily loads were 11.0 kg/d for TCOD, 6.5 kg/d for TDS, 0.7 kg/d for TN and 0.16 kg/d for TP. They constituted only between 22% and 66% of the planned total loads.

During the survey period (May 2013 to October 2013), the mean utilization was 204 usages/d. The total loads and utilization rates were used to determine the mean loads

**Table 2** | Data basis for the calculation of specific loads and comparison with planning data; survey period: May to October 2013

	Planned Mean	Monitored: May 2013–October 2013				n	Monitored ÷ planned
		Mean	SD	Mean: 95% CI	Median		
<b>Water quality</b>							
	mg/L	mg/L	mg/L	mg/L	mg/L	–	%
TCOD	1,667	579	194	501–656	540	23	35
TN	133	38.6	9.6	34.7–42.4	39.0	23	29
TP	16.7	8.8	1.1	8.4–9.2	8.7	23	53
TDS	2,000	377	70.1	361–394	373	68	19
	–	µS/cm	µS/cm	µS/cm	µS/cm	–	–
EC	–	608	113	580–637	601	68	–
<b>Water demand</b>							
	m <sup>3</sup> /d	m <sup>3</sup> /d	m <sup>3</sup> /d	m <sup>3</sup> /d	m <sup>3</sup> /d	–	%
Total	15.0	17.6	4.0	16.8–18.4	15.5	95	117
<b>Utilization rate</b>							
	usages/d	usages/d	usages/d	usages/d	usages/d	–	%
Total	750	204	76.0	188–219	212	95	27
<b>Loads</b>							
a) Total	kg/d	kg/d	kg/d	kg/d	kg/d	–	%
TCOD	25.0	11.0	4.8	9.1–12.9	9.0	23	44
TN	2.0	0.7	0.3	0.6–0.9	0.7	23	37
TP	0.25	0.16	0.03	0.15–0.18	0.16	23	66
TDS	30.0	6.5	2.0	6–7	6.1	68	22
b) Specific	g/usage	g/usage	g/usage	g/usage	g/usage	–	%
TCOD	33.3	45.0	17.4	38.1–52.0	37.3	23	135
TN	2.7	3.0	0.9	2.6–3.4	3.0	23	113
TP	0.33	0.69	0.19	0.61–0.77	0.65	23	207
TDS	40.0	32.0	17.6	27.9–36.2	28.4	68	80

SD = standard deviation, n = number of samples, CI = confidence interval, EC = electrical conductivity.

per usage. They were 45.0 g/usage for TCOD, 31.6 g/usage for TDS, 3.0 g/usage for TN, and 0.69 g/usage for TP. Compared to typical daily per capita loads for developing countries (Von Sperling (2007), Table 2), the specific loads per usage corresponded to 45% of the anticipated daily per capita TCOD load, 26% of the TDS load, 38% of the TN load, and 69% of the TP load. Compared to the anticipated loads per usage, this was lower than expected for TDS (-20%) but higher for TN (+13%), TCOD (+35%) and TP (+107%).

Because greywater represents the largest fraction of the wastewater, the high specific TP loads are most probably caused by phosphates contained in detergents used for laundry washing and showering. TN and TDS have much lower collection rates. These substances are mainly contained in urine and TCOD is mainly contained in feces (Sherwood 2006; Meinzinger & Oldenburg 2009). This finding suggests that users do not explicitly visit the facility for urination but rather for defecation. The relatively high percentage of collected loads compared to planning data indicates that users combine several activities during one visit. The specific loads would be different if billing was carried out differently, e.g., via a fixed monthly fixed fee instead of the pay-per-use model.

The actual number of users is unknown. For instance, a visitor could use the sanitation facility several times per day or only once per week. Considering the anticipated total per capita loads, the collected total daily loads represent 110 population equivalents for TCOD ( $11.0 \text{ kg/d} \times 1,000 \text{ g/kg} \div 100 \text{ g/(capita} \times \text{d)} = 110$  population equivalents), 164 population equivalents for TP, 92 population equivalents for TN, and 54 population equivalents for TDS. Thus, in terms of TCOD loads, the wastewater treatment plant could handle twice the load collected during the survey period.

The lower loads and concentrations compared to planning data were of significance for subsequent treatment steps and reuse options. Because no removal steps were implemented for TDS, TN, and TP in this case, lower loads were not of concern. Lower TDS, TN and TP loads result in lower loads applied via irrigation water and thus lower risks of overfertilization and soil salinization.

The TCOD loads constituted only 44% of the originally planned loads; thus, unintended nitrification occurred

during aerobic treatment. Because a denitrification step or pH adjustment was not projected, the pH decreased during aerobic treatment as the buffering capacity of the water became exhausted. This could cause corrosion in elements of the downstream infrastructure.

Sufficiently high TCOD concentrations are also crucial for the effectiveness of anaerobic treatment steps. Concentrations above 1,500 to 2,000 mg/L are required in the untreated water; otherwise, aerobic treatment should be preferred (Tchobanoglous *et al.* 2004). According to the planning data, TCOD concentrations in the influent should be sufficient for anaerobic treatment. Following implementation, concentrations were below the recommended range. Thus, only aerobic treatment steps should be considered when treating water from shared sanitation.

## CONCLUSIONS

This work focused on planning and implementation of a larger shared sanitation facility in North Namibia. It compared planning and monitoring data on the mean total and specific water demand, mean total and specific loads, utilization rates and concentrations in the untreated water.

The main differences were the higher specific water demand, the lower overall utilization and the lower TCOD, TP, TN and TDS loads and concentrations. The total water demand was roughly the same as anticipated during planning. Greywater constituted the main wastewater flow.

Substances mainly contained in feces and laundry detergents (TCOD, TP) tended to have higher collection rates than substances mainly found in urine (TN, TDS). The mean specific TN, TP and TCOD loads per usage were higher than assumed during planning. The mean specific TDS load was lower.

The lower total loads have several implications for wastewater treatment and reuse. Lower TDS, TP and TN imply lower risks of salinization, overfertilization and eutrophication when reclaiming or discharging the water. Lower TCOD loads render anaerobic treatment unsuitable and may lead to unintended nitrification, a decreasing pH and

corrosion of subsequent infrastructures if no countermeasures are taken.

The increasing tariffs led to a significantly lower utilization, a lower mean water demand and a higher specific water demand. To achieve high utilization, tariffs need to be kept on a low level. The shared sanitation facility should be located in an area with a high population density or at least with a high percentage of built-up area in the surroundings. The specific water use should be controlled for more efficient water use.

Prior work on shared sanitation put emphasis on the general feasibility, institutional and sociological topics and appropriateness. Information on the expectable utilization and water quantities is limited. No information on the water demand per usage, concentrations or specific and total loads of common wastewater parameters has been published so far. The results obtained from this study thus contribute significantly to fill this gap. This is particularly valuable for better planning of wastewater transport, treatment and reuse.

Future studies should include further aspects and influencing factors such as population density, available income, or the influence of competing facilities. With such information, the planning of shared sanitation facilities and their integration into a comprehensive sanitation approach could be facilitated.

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