

Research Paper

Septage composition and pollution fluxes from cesspits in Palestine

Belal Amous, Nidal Mahmoud, Peter van der Steen
and Piet N. L. Lens 

ABSTRACT

The cesspit septage quality and pollution loads of total nitrogen (TN) and heavy metals (HMs) from 50 cesspits were assessed during various filling periods. The average specific wastewater production, emptied septage and infiltrated septage were 49, 30 and 19 L/c d, respectively. The TN specific loads of septage fractions that were emptied and infiltrated were 8.5 and 3.3 g/c d, respectively. The concentrations of HMs (mg/L) in the septage were Cu (0.24), Ni (0.03), Pb (0.01), Mn (0.47), Fe (12.6), Cr (0.04) and Zn (1.23). The septage content of Cu, Mn and Fe did not comply with the Palestinian regulations for wadi disposal nor effluent reuse in agriculture. The specific TN infiltration from cesspits amounts to 29 kg TN/ha y. There was no relation between the HM and TN content of septage and the desludging frequency. The infiltrated septage contributed to as much as 15% of the total groundwater recharge in the study area. This study confirms that cesspits in Palestine should be replaced with proper wastewater management systems for adequate environmental protection.

Key words | assessment, cesspit, heavy metals, on-site, septage, total nitrogen

HIGHLIGHTS

- Septage from cesspits is nitrogen rich, and so a major groundwater pollution source.
- No relations exist between the HM and TN in septage and the desludging frequency.
- The infiltrated septage contributed to 15% of the total groundwater recharge.
- Soil is an effective filter for HM. But, the emptied septage is rich in HM.
- Heavy metal concentration in septage is high for wadi disposal or agricultural use.

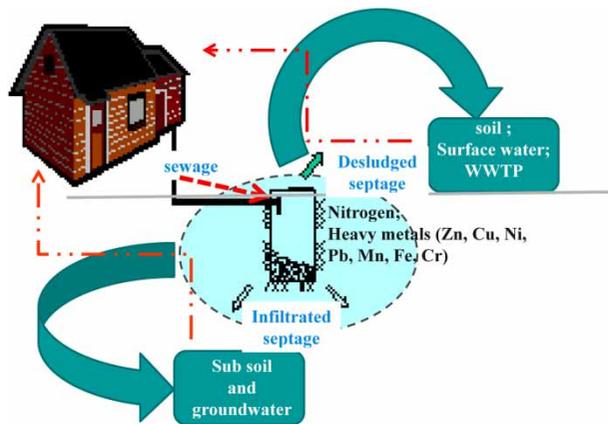
Belal Amous

Nidal Mahmoud (corresponding author)
Institute of Environmental and Water Studies,
Birzeit University,
P.O. Box 14, Birzeit, West Bank,
Palestine
E-mail: nmahmoud@birzeit.edu

Peter van der Steen

Piet N. L. Lens 
IHE-Delft Institute for Water Education,
P.O. Box 3015, Delft 2601 DA,
The Netherlands

GRAPHICAL ABSTRACT



INTRODUCTION

Poor sanitation remains one of the greatest challenges of the 21st century as nearly 90% of the generated sewage in less developed countries (LDC) and 20% in more developed countries (MDC) are disposed untreated into nature (WWAP 2017). The consequences are devastating since poor sanitation and contaminated drinking water resources cause more than 80% of all diseases in the developing world (Afolabi & Sohail 2017). In low-income countries, septic tanks and pit latrines represent the predominant compulsory solution currently meeting the sanitation needs of more than 2.7 billion people worldwide (Strande *et al.* 2014; Jenkins *et al.* 2015). In order to provide these countries with new infrastructure and appropriate technologies to increase the treatment and use of wastewater, significant investments will be required (Sato *et al.* 2013). About 60% of the West Bank (Palestine) households rely on cesspit sanitation systems (PCBS 2018). Cesspits are unlined underground pits similar to the pits used with pit latrine systems that capture wastewater and sewage and simply collect it. The present practice of cesspits' septage disposal is mainly via an uncontrolled discharge in nearby wadis (a wadi refers to a valley that has a river that is usually dry except when it has rained), and to a much lesser extent in public sewerage networks (PWA 2012).

A growing number of case studies have documented a trend of nitrate contamination in urban groundwater

across the world (Wang *et al.* 2017; Ndoziya *et al.* 2019). Many of them identified sewage from un-sewered low-income residential areas as the pollution source. Leaching of liquid to soils from cesspits is a hidden source of diffuse pollution to groundwater since leaching often occurs sub-surface, and occurs usually at slow rates (Wang *et al.* 2017).

The largest chemical concerns for groundwater pollution from on-site sanitation systems are nitrogen and heavy metals (HMs) (Strande *et al.* 2014). HMs, such as lead and cadmium, are excreted in human faeces (Schouw *et al.* 2002; Bassan *et al.* 2013; Afolabi & Sohail 2017; Krithika *et al.* 2017) and as such may provide a residual source of contaminants in cesspits' septage. Though septage contains plant nutrients such as nitrogen, phosphorus, and in some cases, varying amounts of HMs as copper, zinc, lead and manganese (Stefanakis & Tsihrintzis 2011). Although HMs in house applications are limited, HMs enter domestic sewage from different sources such as cleaning agents, paints, pesticides, rechargeable batteries and other household chemicals (EC 2001).

Characteristics of septage from septic tanks are highly variable, depending on climate, user habits, septic tank size, design, pumping frequency and water supply characteristics (Krithika *et al.* 2017). The design and operation of treatment plants rely on accurate knowledge of septage characteristics (organic content in terms of biochemical

oxygen demand (BOD), HMs and nitrogen concentration) (Bassan *et al.* 2013), but this information about septage from cesspits, particularly nitrogen and HMs, is lacking in Palestine and nearby countries like Jordan (Halalsheh *et al.* 2010). Besides, these data are crucial to assess the environmental impact of cesspits as a consequence of septage infiltration and disposal in open areas. The Palestinian environmental regulations set maximum limits for the pollutant concentrations in waste streams, like industrial wastewater and septage, to be disposed in public sewage networks or in nature. Strande *et al.* (2014) reported that a complete inactivation of the nitrification process was observed in a wastewater treatment plant (WWTPs) in South Africa, which took several months to recover. A hypothesis suggests that the excessive nitrogen load discharged into the plant was the main reason, but the causes of the problem are unclear. In addition to organic and nitrogenous compounds, HMs likely present in septage are of concern as well (Krithika *et al.* 2017).

The objective of this research was to characterise septage from cesspits in terms of nitrogenous compounds (total Kjeldahl nitrogen (TKN) and nitrate (NO_3^-)) and heavy metal (Zn, Cu, Ni, Pb, Mn, Fe and Cr) concentrations from various household cesspits with different desludging frequency periods, as well as to determine the specific pollution fluxes in terms of litre per capita per day (L/c d) and the specific pollution loads (g/c d) of total nitrogen (TN) and HM from cesspits. This study focussed on nutrients and metals, but did not consider the organic load of the septage, which is also very important for the design of WWTP, but had already been characterised previously (Al-Atawneh *et al.* 2016).

MATERIALS AND METHODS

Study area

The adjacent residential villages Beit Dajan and Beit Fourik are located in the middle part of the West Bank (Palestine), 10 km east of Nablus city. The majority of people in the study area are living in single un-sewered separate houses. The population of Beit Dajan and Beit Fourik were 3,958, 11,741 and 2,719,112 persons, respectively (PCBS 2018).

Household survey

A questionnaire was filled out through direct meetings with household owners and staff from municipalities. About 200 questionnaires were collected from both villages. The structured questionnaire was specifically designed for this study that covered family size and age distribution, sources of water supply and use, wastewater disposal method and cesspits desludging frequencies. The frequency of cesspits desludging was also obtained from the archived records of the driver of the vacuum truck that emptied the cesspits in the study area.

Septage characteristics and pollution fluxes

Fifty septage samples were collected from 50 different individual cesspits located in the Beit Dajan and Beit Fourik villages, each cesspit served one household or a cluster of households, with different desludging frequencies over 5 months. Samples were collected from the vacuum truck, through a tap installed on its storage tank, after emptying each individual home cesspit to ensure complete mixing of the septage; meaning that each sample of the 50 samples represented one unique house of specific desludging frequency. The collected samples of each individual cesspit were stored in separate bottles in a cooling box at 4 °C and directly transferred to the laboratory for analysis within less than 1 h.

Infiltration of septage from cesspits

Infiltrated septage samples were collected from a sampling well, designed and installed for this study, near a single household cesspit to collect the infiltrated septage (Figure 1). The monitoring well was made by installing a 75 mm PVC pipe of 6 m length in a hole dug out near a cesspit. The pipe was installed 0.5–1.0 m away from the cesspits, while it went down almost 1.5–2.0 m below its bottom since the depth of the cesspit was around 4 m. The bottom end of the pipe was sealed, whereas the sides were perforated 15 cm above the bottom end to enable flow of the infiltrated septage. The system was monitored twice weekly after being installed. Infiltrated septage started to accumulate 4 months after installation, and five samples were drawn manually

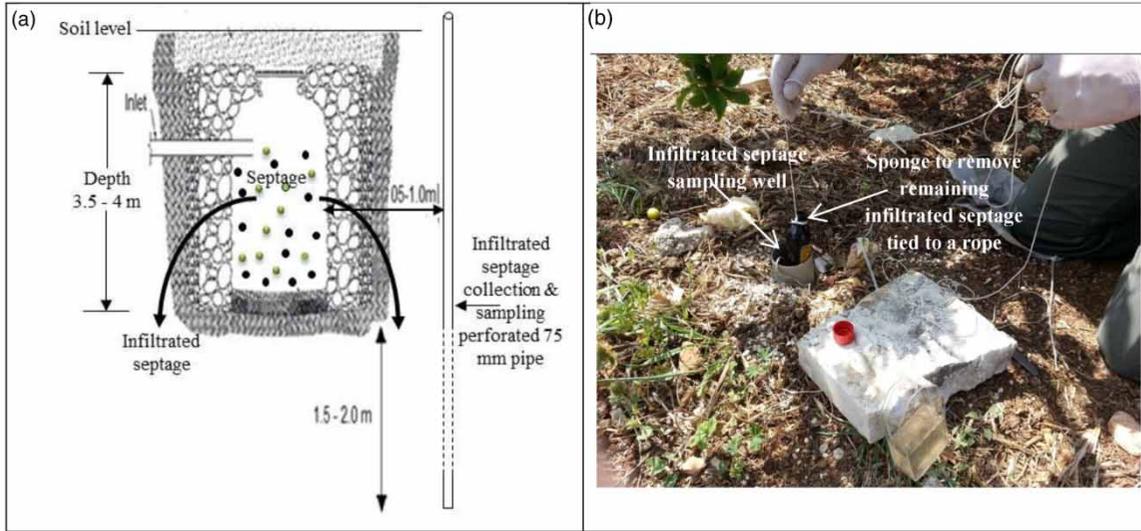


Figure 1 | (a) Cesspit schematic drawing and (b) infiltrated septage sampling well in Beit Dajan.

during the subsequent 3-month period. The samples were collected from the well by a 100 mL bottle tied to a rope. After each sampling, the remaining infiltrated septage in the well was removed by a sponge to ensure the collection of fresh infiltrate. In addition, septage samples were also collected from the cesspit to compare with septage quality after infiltration through the soil. Due to technical limitations, monitoring of infiltrated liquid was limited to only a single cesspit location, which is a rather limited sample size.

Analytical methods

The cesspit and infiltrated septage samples were analysed for TKN, NO_3^- and HMs according to standard methods (APHA 2005). Nitrate was analysed using the capillary ion analyser (CIA) method. HMs were determined in duplicate samples that were subjected to acid digestion and then analysed by Inductively Coupled Plasma (ICP) Mass Spectrophotometry (ICP OPTIMA 3000 Perkin Elemer).

Mass balance, recharge and pollutant load estimations calculations

The mass balance calculations of water and the measured parameters for assessing the pollution fluxes from each of the 50 cesspits were carried out based on the following

equations:

$$\text{Volume of infiltrated septage from the cesspit to the surrounding soil} = \text{volume of sewage produced over the filling period} - \text{emptied septage volume} \quad (1)$$

Evaporation was neglected as the cesspit was a closed system, and evaporation was estimated to be less than 1% of the collected wastewater, calculated based on 1 mm/d evaporation.

$$\text{Specific TN}_{\text{emptied septage}} \text{ (g/c} \cdot \text{d)}$$

$$= \frac{Q_{\text{emptied septage}} \times \text{TN}_{\text{emptied septage}}}{\text{number of household inhabitants}} \quad (2)$$

$$\text{Specific TN}_{\text{infiltrated septage}} \text{ (g/c} \cdot \text{d)}$$

$$= \frac{Q_{\text{infiltrated septage}} \times \text{TN}_{\text{infiltrated septage}}}{\text{number of household inhabitants}} \quad (3)$$

$$\text{Specific TN}_{\text{total septage}} \text{ (g/c} \cdot \text{d)}$$

$$= \text{Specific TN}_{\text{emptied septage}} + \text{Specific TN}_{\text{infiltrated septage}} \quad (4)$$

$$\text{Population}_{\text{year } n} = \text{Population}_{\text{year 2013}}(1 + Gr^n) \quad (5)$$

$$\text{Annual TN}_{\text{infiltrated}} \text{ (kg N/y)}$$

$$= \text{Annual TN}_{\text{infiltrated from periodically emptied cesspits}} + \text{Annual TN}_{\text{infiltrated from never emptied cesspits}} \quad (6)$$

where:

$$\begin{aligned} \text{Annual TN}_{\text{infiltrated from periodically emptied cesspits}} \text{ (kg N/y)} \\ = \text{Specific TN}_{\text{infiltrated septage}} \times \text{number population} \\ \times 365.25 \times \% \text{ cesspits periodically emptied} \end{aligned} \quad (7)$$

$$\begin{aligned} \text{Annual TN}_{\text{infiltrated from never emptied cesspits}} \text{ (kg N/y)} \\ = \text{Specific TN}_{\text{total septage}} \times \text{number population} \\ \times 365.25 \times \% \text{ cesspits never emptied} \end{aligned} \quad (8)$$

$$\text{Total nitrogen load (kg N/ha} \cdot \text{y)} = \frac{\text{Annual TN}_{\text{infiltrated}}}{\text{Area (ha)}} \quad (9)$$

$$\begin{aligned} \text{Total groundwater recharge (m}^3\text{/y)} \\ = \text{recharge from precipitation} \\ + \text{recharge from cesspits} \end{aligned} \quad (10)$$

The amount of septage infiltrated from cesspits was calculated by multiplying the specific infiltrated septage (L/c d), presented in Table 1, by the population number.

Statistical data analysis

Statistical analysis and data processing were carried out using the Statistical Package for the Social Sciences (SPSS), version 20.0. Pearson's correlation was computed and tested for significance to assess the relationship between the nitrogen or HM concentration and the desludging period.

Table 1 | Water consumption and fate of generated wastewater collected in cesspits in Beit Dajan and Beit Fourik

	Unit	Average	Range
Family size ^a	Person	10 (4.9)	2–23
Water consumption	L/c d	58 (11.5)	40–90
Desludging interval ^b	d	134 (200)	10–720
Wastewater generated	L/c d	49 (9.5)	35–75
Specific emptied septage ^c	L/c d	30 (11.6)	4–48
Specific infiltrated septage ^d	L/c d	19 (12.5)	2–53

Standard deviations are in parentheses.

^aFamily term represents household or cluster of households sharing the same cesspit.

^bFrom the records of the vacuum truck driver.

^cCalculated from the records of the vacuum truck driver and survey results.

^dCalculated by Equation (1) divided by the household number of inhabitants.

RESULTS AND DISCUSSION

Baseline data

The survey results revealed that the cesspit system is the only wastewater disposal method in the study area (Table 1). Cesspits receive an average of 85% of the consumed fresh water within households, whereas the other 15% is used for outdoor activities. Of the surveyed houses, 85% of the cesspits are emptied at various intervals, while 15% are never emptied. The majority of the surveyed houses emptied their cesspits in less than a year, approximately 71% of the cesspits (Figure 2). Cesspit desludging might cost up to 30% of a family monthly income.

Cesspits septage characteristics

Total nitrogen

The results of the TN concentrations in the cesspits septage and the specific cesspit septage nitrogen loads are presented in Table 2. Nitrate was not found in the septage because of the prevailing anaerobic conditions, thus TN is equivalent to TKN (Metcalf & Eddy 2013). The TN concentration in septage is higher than that of raw domestic wastewater in Palestine by a factor of around three as the TN concentration of Al-Bireh city is around 100 mg/L (Mahmoud *et al.* 2003). Nevertheless, it falls within the range of TN of septage reported in the USA (66–1,060 mg/L), but closer to the lower limit (U.S. EPA 2002).

The TN did not significantly decrease as family size increased (Figure 3(a)). Pearson's coefficient computed between the nitrogen concentration and desludging period revealed no significant positive correlation ($r = 0.28$). Likewise, Al-Atawneh *et al.* (2016) found no significant variation in the average TN values of septage during the 4-month filling period of a cesspit in Beit Dajan. Therefore, the TN concentration of septage in Palestine can be generalised regardless the cesspit desludging frequency, when this is more than 10 days (Figure 3(b)). The pollution fluxes and specific nitrogen pollution loads in Beit Dajan and Beit Fourik (Palestine) are presented in Tables 1 and

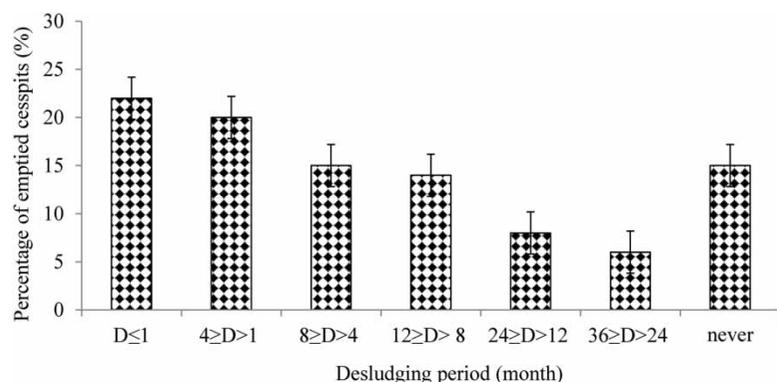


Figure 2 | Percentage of cesspits with various monthly desludging periods (D) in the villages Beit Dajan and Beit Fourik.

Table 2 | TN content and specific TN for total, emptied and infiltrated septage fluxes in Beit Dajan and Beit Fourik (Palestine)

		Average	Range
TN emptied septage ^{a,c}	mg/L	297 (89)	171–517
TN infiltrated septage ^{b,c}	mg/L	159 (47.7)	92–277
Specific TN _{emptied septage}	g/c d	8.53 (3.75)	1.26–17.73
Specific TN _{infiltrated septage}	g/c d	3.27 (2.60)	0.21–11.91
Specific TN _{total septage}	g/c d	11.8 (3.85)	4.3–22

Standard deviations are in parenthesis.

^aAverage values of septage for 50 individual cesspits.

^bTN_{infiltrate} = TN_{septage} × 53.6%.

^cThe total nitrogen concentration (TN) = TKN + NO₃-N, but since nitrate in all of the analysed samples was not detected, the nitrate concentration was considered zero and thus the TN = TKN.

2, respectively. The specific TN in the total septage of the study area of 11.8 g/c d (Table 2) is very close to the specific TN production rate of 10 g/c d in raw wastewater from an individual home in Beit Dajan (Al-Atawneh *et al.* 2016), and 11 g/c d for Al-Bireh/Palestine municipal raw sewage (sewered) (Mahmoud *et al.* 2003). This reveals, from the mass balance, that TN had not been removed out of the septage, i.e. via the gas phase nor via chemical precipitation.

Heavy metals

The major HMs in cesspit septage are Fe, Mn, Cu and Zn (Table 3). The most abundant heavy metal was Fe, which is in conformity with previously obtained results of a single household septage by Al-Atawneh *et al.* (2016). The high Fe concentration is most likely due to solubilisation of

iron from the ferric to ferrous form under completely anaerobic conditions in a cesspit (Al-Atawneh *et al.* 2016). Guyton & Hall (2000) showed that iron is one of the major components of the inorganic fractions of faecal solids. For Ni, Pb and Cr, the average values were so small, and taking into account the STD, these concentrations are not statistically different from the detection limit of the ICP. Generally, the concentrations of HMs found in faecal sludge are relatively low and in most cases less than 2 mg/c d – with the exception of Zn, which can be up to 16 mg/c d (Afolabi & Sohail 2017). Similarly, Al-Atawneh *et al.* (2016) reported higher heavy metal concentrations in septage of a single household as compared to raw sewage due to accumulation (Table 3). Al-Atawneh *et al.* (2016) reported septage pH values in the here investigated study area to be close to neutral, at which most HMs form precipitates resulting in HMs accumulation inside the cesspit. Pearson's coefficient computed between the HM concentrations and desludging period revealed no significant correlation ($-0.19 < r < 0.197$).

The references and standard values presented in Table 3 reveal that the heavy metal (Cu, Pb, Mn, Fe and Zn) content is not always in compliance with the heavy metal concentration limits according to the Palestinian regulations neither for wadi disposal nor for effluent reuse in agriculture. Likewise, Bassan *et al.* (2013) reported HMs in faecal sludge collected from pit latrines in the Ouagadougou capital of Burkina Faso of Zn (8.0 mg/L), Cu (1.2 mg/L), Fe (21.0 mg/L) and Pb (0.7 mg/L). These values of HMs exceeded the discharge limit to water bodies for Burkina Faso of Zn (5 mg/L), Cu (1 mg/L), Fe

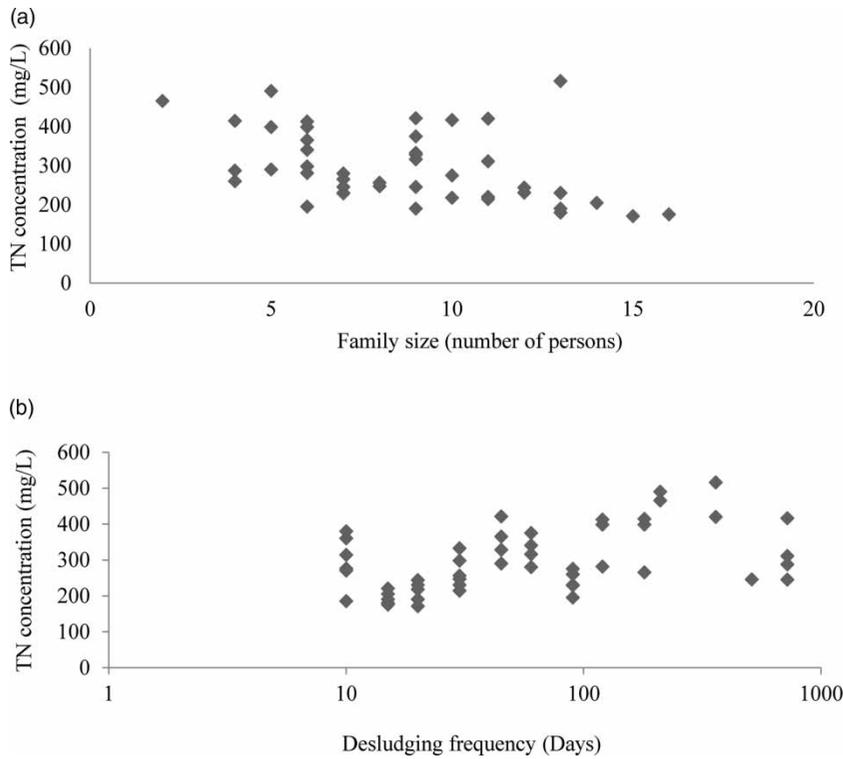


Figure 3 | Impact of (a) family size and (b) cesspit emptying frequency on the TN concentration of septage.

(20 mg/L) and Pb (0.5 mg/L). *Krithika et al. (2017)* reported HMs (aluminium, barium, calcium, cadmium, cobalt, chromium, copper, iron, potassium, magnesium, manganese, molybdenum, nickel, lead, strontium, titanium, vanadium and zinc) in the septage solids collected from septic tanks with concentrations considerably lower than those typically observed in domestic sewage sludge. Apparently, the HMs content in septage generated from septic tanks is less than that from cesspits.

The Palestinian ministerial cabinet resolution number (16) concerns with the requirements of institutions connection to the public sewerage system (*PMC 2013*). According to the resolution, pollutant concentrations in the effluents to be allowed to be connected to the public sewerage system shall not exceed the identified limits (*Table 3*). As per these regulations, the heavy metal concentrations in the septage allow the septage disposal in the septage receiving unit of the municipal WWTPs to be further treated. This is coherent with the Sustainable Development Goal (SDG) 6.2 that calls for safely managed sanitation services including the septage (*WWAP 2017*).

Quality of infiltrated septage

Total nitrogen

The TN concentration inside the specific cesspit, where the infiltration pipe was installed, and in the concurrent infiltrated septage were 233 (24) mg/L and 125 (0.6) mg/L, respectively. This entails that the percentage of TN concentration in the infiltrated septage is 53.6% of the TN concentration in the septage inside the cesspit. The amount of nitrogen that might reach the groundwater or might adsorb onto soil could not be quantified. *Dawes & Goonetilleke (2006)* reported that the greatest removal of nitrogen occurred within 1 m of the surrounding soil, with negligible further removal between 1 and 3 m from the septic system. This indicates that particulate nitrogenous compounds are retained physically due to the soil filtering characteristics within this short distance since nitrification is impossible to occur under anaerobic conditions.

In case the nitrogenous compounds are oxidised to nitrate, then nitrate can travel through the unsaturated

Table 3 | Heavy metal concentrations in cesspit septage in Beit Dajan and Beit Fourik, Al-Bireh city septage as well as raw and treated sewage in an extended aeration system compared with standards and guidelines

		Cu	Ni	Pb	Mn	Fe	Cr	Zn	Reference
Septage (Beit Dajan and Beit Fourik)	Avg.	0.24 (0.26)	0.03 (0.05)	0.01 (0.02)	0.47 (0.39)	12.56 (8.6)	0.04 (0.03)	1.23 (1.83)	This study
	Range	0.0–1.56	0.0–0.23	0.0–0.10	0.08–2.54	2.18–44.8	0.0–0.17	0.08–7.56	This study
Raw wastewater (a one household in Beit Dajan)	Avg.	0.213 (0.081)	0.000 (0.000)	0.007 (0.019)	0.115 (0.059)	1.567 (1.284)	0.005 (0.014)	0.711 (0.947)	Al-Atawneh <i>et al.</i> (2016)
Septage (a one household in Beit Dajan during the cesspit filling period)	Avg.	0.399 (0.170)	0.038 (0.023)	0.18 (0.077)	0.790 (0.386)	23.685 (8.980)	0.055 (0.018)	2.937 (0.962)	Al-Atawneh <i>et al.</i> (2016)
Concentration factors ^a	Avg.	1.87	≥2.5	≥3.6	6.9	15	≥3.66	4.13	Al-Atawneh <i>et al.</i> (2016)
Al-Bireh city raw sewage	Avg.	0.221	0.075	N/A	N/A	N/A	0.163	1.364	Samara (2009)
	Max	0.72	0.117	N/A	N/A	N/A	0.227	3.496	Samara (2009)
Al-Bireh city treated effluent	Avg.	0.11	0.03	N/A	N/A	N/A	0.057	0.478	Samara (2009)
	Max	0.207	0.047	N/A	N/A	N/A	0.089	1.480	Samara (2009)
Palestinian standards/treated sewage discharge to wadis		0.20	0.20	0.10	0.20	2.00	0.50	5.0	PSI (2015)
Palestinian specifications for agricultural use		0.20	0.20	0.20	0.20	5.00	0.10	2.0	PSI (2015)
Max. HMs to be discharged in the public sewers		4.50	4.00	0.60	N/A	50	5.00	15.00	PMC (2013)
FAO guidelines for max. HMs		0.20	0.20	5.00	0.20	5.00	0.10	2.00	FAO (1992)

All parameters are in mg/L; N/A: not available. The '0' heavy metal concentration stands for below detection limit. Standard deviations are in parenthesis.

^aConcentration factor = heavy metal concentration in septage/heavy metal concentration in raw wastewater.

soil zone to groundwater, as it does not interact with soil components under aerobic conditions, noting that groundwater in Palestine is aerobic (PWA 2012). Once nitrate reaches the groundwater, it will not undergo further transformation, unless conditions for denitrification exist.

The presence of nitrate in the water of the supplying well of Beit Dajan and Beit Fourik at 20 mg NO₃⁻/L, based on the Palestinian Water Authority database, indicates that there is a source of nitrate pollution. Since groundwater in the West Bank is aerobic, cesspits are claimed to be the source of pollution in the study area in the absence of any other major source of nitrogen. Assuming that the percentage of TN concentration in the infiltrated septage of 53.6% is similar in all cesspits, since

all are located in the same geographical area and have the same soil type (terra rossa type), the quality of infiltrate in terms of TN is presented in Table 2. The annual specific nitrogen loads (kg/c-y) of the infiltrated, emptied and total septage are 1.2, 3.1 and 4.3, respectively (Equations (6)–(8)). The typical international reported annual specific nitrogen loads (kg/c-y) from wastewater are 4–5 kg/c-y (Borst *et al.* 2013).

Heavy metals

The heavy metal concentrations inside the specific cesspit, where the infiltration pipe was installed, have reduced dramatically after their passage through the soil. The heavy metal concentrations (in mg/L) in the septage inside the

cesspit and the infiltrated septage were, respectively: Cu (0.2; 0), Ni (0.03; 0), Pb (0; 0), Mn (0.23; 0.008), Fe (4.35; 0.32), Cr (0.019; 0) and Zn (0.66; 0.02). Cu, Ni and Cr were not detected in the infiltrate and have thus been removed from the septage. The concentrations of other metals such as Mn, Fe and Zn have been dramatically reduced and were detected only in trace concentrations. Therefore, the here initial investigation reveals that the pollution load from the infiltrated septage in terms of HMs can be considered minimal when considering its impact on groundwater quality. Although metals are stable, i.e. cannot be degraded, they can be transformed to other oxidation states, thus reducing their mobility. Metal mobility in soils is reduced by adsorption, precipitation or microbial activity, i.e. hydrolysis, precipitation, chelation, biomethylation or volatilisation of HMs (Wuana & Okieimen 2011). Al-Atawneh *et al.* (2016) reported septage pH values in the here investigated study area to be close to neutral, at which most HMs form precipitates. Although a substantial amount of HMs thus accumulated inside the cesspit, it is still not known how much the HMs have also been adsorbed onto the soil in the vicinity of the cesspits, which calls for further investigations.

Contribution of cesspits to groundwater recharge and nitrogen content

Assuming all infiltrated septage reaches groundwater, it was estimated that it makes about 6.7% of the total recharge to groundwater from Beit Dajan and 18.7% of Beit Fourik (Equation (10); Table 4). Although the population of Beit Fourik is three times that of Beit Dajan, the village area is smaller than that of Beit Dajan. Therefore, Beit Dajan

receives more precipitation than Beit Fourik. Wastewater recharge in the study area, viz. both Beit Dajan and Beit Fourik, thus contributes to as much as 13% of the total recharge from precipitation, making cesspits a significant source of recharge bearing in mind that the study area has a low population density. This percentage may significantly increase when considering areas with a higher population density, like cities or refugee camps in Palestine. Similarly, in a case study of the urban areas in Sub-Saharan Africa, septage recharge was estimated to be as high as 10–50% of the total amount of precipitation (Nyenjea *et al.* 2013). The TN load in the study area is estimated to be 28.7 kg/ha y in the year 2013 (Equation (9)).

CONCLUSIONS

The specific TN infiltrating from cesspits in Palestine amounts to 29 kg TN/ha·y. The TN specific loads of total septage and its two fractions that were emptied and infiltrated were 11.8, 8.5 and 3.3 g/c·d, respectively. The results show no relation between the HM or TN content of septage and the desludging frequency. The specific wastewater production, emptied septage and infiltrated septage were 49, 30 and 19 L/c·d, respectively. The HM concentrations of Mn, Fe and Zn in the infiltrated septage were dramatically reduced after being filtered through the surrounding soil, and the HM concentrations of Cu, Ni and Cr were below the detection levels. The HM content in septage is high, and not in compliance with the Palestinian regulations for wadi disposal nor for effluent reuse in agriculture. However, septage HM concentrations allow septage disposal in municipal WWTPs.

Table 4 | Contribution of cesspits to groundwater recharge

Locality	Area (ha)	Recharge from precipitation (m ³ /y) ^a	Recharge from cesspits (m ³ /y) ^b	Cesspits contribution to recharge (%)
Beit Dajan	5,00	471,000	33,996	6.7
Beit Fourik	465.8	439,061	100,839	18.7
Total	965.8	910,061	134,835	13.0

^aCalculations are based a mean annual rainfall in the study area of 377 mm/y, and 25% of the total precipitation is recharged to groundwater as reported by the Palestinian Water Authority (PWA 2012).

^bThe average septage infiltrated from cesspits is 19 L/c d (Table 1).

ACKNOWLEDGEMENTS

This study was carried out under the framework of the project 'Impact of untreated wastewater on natural water bodies: Integrated risk assessment (UWIRA)', financially supported by the Dutch Government (DGIS) under IHE Partnership Research Fund (UPaRF).

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

- Afolabi, O. O. D. & Sohail, M. 2017 [Microwaving human faecal sludge as a viable sanitation technology option for treatment and value recovery – a critical review](#). *Journal of Environmental Management* **187**, 40–415.
- Al-Atawneh, N., Mahmoud, N., van der Steen, P. & Lens, P. N. L. 2016 [Characterisation of septage in partially sealed cesspit](#). *Journal of Water, Sanitation and Hygiene for Development* **6** (4), 631–639.
- APHA 2005 *Standard Methods for the Examination of Water and Wastewater*, 21st edn. American Public Health Association, Washington, DC.
- Bassan, M., Tchonda, T., Yiougo, L., Zoellig, H., Mahamane, I., Mbéguéré, M. & Strande, L. 2013 [Characterization of faecal sludge during dry and rainy seasons in Ouagadougou, Burkina Faso](#). In *36th WEDC International Conference*, Nakuru, Kenya.
- Borst, B., Mahmoud, N. J., van der Steen, N. P. & Lens, P. N. L. 2013 [A case study of urban water balancing in the partly seweraged city of Nablus-East \(Palestine\) to study wastewater pollution loads and groundwater pollution](#). *Urban Water Journal* **10** (6), 434–446.
- Dawes, L. & Goonetilleke, A. 2006 [Using multivariate analysis to predict the behaviour of soils under effluent irrigation](#). *Water, Air, and Soil Pollution* **172** (1–4), 109–127.
- EC (European Communities) 2001 *Pollutants in Urban Waste Water and Sewage Sludge – Final Report*. Office for Official Publications of the European Communities, Luxembourg, p. 273.
- FAO (Food and Agricultural Organization of the United Nations) 1992 *Wastewater Treatment and Use in Agriculture – FAO Irrigation and Drainage Paper 47*. FAO Corporate Document Prosperity, Rome, Italy.
- Guyton, A. C. & Hall, J. E. 2000 *Textbook of Medical Physiology*, 10th edn. W.B. Saunders Company, Philadelphia.
- Halalsheh, M. M., Noaimat, H., Yazajeen, H., Cuello, J., Freitas, B. & Fayyad, M. 2010 [Biodegradation and seasonal variations in septage characteristics](#). *Environmental Monitoring and Assessment* **172** (1–4), 419–426.
- Jenkins, M. W., Cumming, O. & Cairncross, S. 2015 [Pit latrine emptying behaviour and demand for sanitation services in Dar es Salaam, Tanzania](#). *International Journal of Environmental Research and Public Health* **12**, 2588–2611.
- Krithika, D., Thomas, A. R., Iyer, G. R., Kranert, M. & Philip, L. 2017 [Spatio-temporal variation of septage characteristics of a semi-arid metropolitan city in a developing country](#). *Environmental Science and Pollution Research* **24** (8), 7060–7076.
- Mahmoud, N., Amarneh, M. N., Al-Sa'ed, R., Zeeman, G., Gijzen, H. & Lettinga, G. 2003 [Sewage characterization as a tool for the application of anaerobic treatment in Palestine](#). *Environmental Pollution* **126** (1), 115–122.
- Metcalf & Eddy 2013 *Wastewater Engineering: Treatment and Resource Recovery*, 5th edn. McGraw-Hill Education, New York.
- Ndoziya, A. T., Hoko, Z. & Gumindoga, W. 2019 [Assessment of the impact of pit latrines on groundwater contamination in Hopley Settlement, Harare](#). *Journal of Water, Sanitation and Hygiene for Development* **9** (3), 446–476.
- Nyenjea, P. M., Foppen, J. W., Kulabako, R., Muwanga, A. & Uhlenbrook, S. 2013 [Nutrient pollution in shallow aquifers underlying pit latrines and domestic solid waste dumps in urban slums](#). *Journal of Environmental Management* **122**, 15–24.
- PCBS (Palestinian Central Bureau of Statistics) 2018 *Housing Conditions Survey 2018*. Ramallah, Palestine.
- PMC (Palestinian Ministerial Cabinet) 2013 *Palestinians Ministerial Cabinet Resolution Number (16) for the Year 2013 Regarding the 'the System of Houses and Facilities Connection to the Public Sewage Network'*.
- PSI (Palestinian Standards Institution) 2015 *Treated Wastewater – Treated Wastewater Effluent for Agricultural Purposes, Palestine Standard: PS 742-2015*, 2nd edn. Treated Wastewater Standards, Ramallah, Palestine.
- PWA (Palestinian Water Authority) 2012 *Annual Water Status Report 2011*.
- Samara, N. M. 2009 [Heavy Metals Concentration in Biosolids of Al-Bireh Sewage Treatment Plant and Assessment of Biosolids Application Impacts on Crops Growth and Productivity](#). MSc Thesis, Birzeit University, Palestine.
- Sato, T., Qadir, M., Yamamoto, S., Endo, T. & Zahoor, A. 2013 [Global, regional, and country level need for data on wastewater generation, treatment, and use](#). *Agricultural Water Management* **130**, 1–13.
- Schouw, N. L., Danteravanich, S., Mosbaek, H. & Tjell, J. C. 2002 [Composition of human excreta- a case study from Southern Thailand](#). *Science of the Total Environment* **286** (1–3), 155–166.
- Stefanakis, A. I. & Tsihrintzis, V. A. 2011 [Dewatering mechanisms in pilot scale sludge drying reed beds: effect of design and](#)

- operational parameters. *Chemical Engineering Journal* **172** (1), 430–443.
- Strande, L., Ronteltap, M. & Brdjannovic, D. 2014 *Faecal Sludge Management: Systems Approach for Implementation and Operation*. IWA Publishers, London.
- U.S. EPA 2002 *On-site Wastewater Treatment Systems Manual* (Chaps. 1 and 4). U.S. EPA, Office of Water, Office of Research and Development, Washington, DC, pp. 6–34.
- Wang, S., Zheng, W., Currell, M., Yang, Y., Zhao, H. & Lv, M. 2017 [Relationship between land-use and sources and fate of nitrate in groundwater in a typical recharge area of the North China Plain](#). *Science of the Total Environment* **609**, 607–620.
- Wuana, R. & Okieimen, F. 2011 [Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation](#). *ISRN Ecology* **2011**, 402647. doi:10.5402/2011/402647
- WWAP (United Nations World Water Assessment Programme) 2017 *The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource*, UNESCO, Paris.

First received 17 May 2020; accepted in revised form 8 August 2020. Available online 16 September 2020