Research Paper

Assessment of the impact of pit latrines on groundwater contamination in Hopley Settlement, Harare, Zimbabwe

Alfonse Tapera Ndoziya, Zvikomborero Hoko and Webster Gumindoga

ABSTRACT

A study was conducted to assess the water quality of the groundwater sources and possible impacts of pit latrines on the groundwater for selected boreholes and wells. The City of Harare's peri-urban settlement of Hopley predominantly uses pit latrines for excreta disposal. This puts groundwater at risk to contamination thereby threatening human health. Pit latrine density around groundwater points was assessed using a Geographical Information System (GIS). The pit latrine density ranged from 0 to 5 latrines in a 15 m radius to 3–63 latrines in a 100 m radius. From the analysis of the water samples, it was observed that on average, only 63% and 48% of samples met drinking water quality standards set by the World Health Organization guidelines and Standards Association of Zimbabwe limits. Principal component analysis (PCA) showed that only three components had an eigenvalue of over 1 that explained 76.9% of the total cumulative variance of the observed variable. From the PCA, key parameters in groundwater contamination were nitrates, electrical conductivity, chlorides, ammonia, and thermotolerant coliforms. The spatial variation of the selected water quality parameters suggests that water points at the lowest end of the settlement had the poorest water quality. The point-of-use treatment is recommended for wells.

Key words | GIS, groundwater, peri-urban, pit latrine, principal component analysis, water quality

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INTRODUCTION

It is estimated that 70% of the people in the Southern African Development Community (SADC) region rely on groundwater as a major source of drinking water and, in most cases, consumed without receiving treatment to improve quality (Rosa & Clasen 2010). Peri-urban areas are often characterised by heavily compromised groundwater, with excess levels of nitrate, chloride and microbial pathogens (Xu & Usher 2006). There is a concern that chemical and microbial contaminants in pit latrines can leach into groundwater sources thereby threatening human health (Dzwairo *et al.* 2006; Graham & Polizzotto 2013). Previous studies on the impacts of pit latrines on groundwater quality have demonstrated deterioration in groundwater quality (Haruna *et al.* 2005; Graham & Polizzotto 2013). Thus, the protection of groundwater sources from pollution by pit latrines is critical. There is strong evidence that access to improved sanitation and safe drinking water can reduce diarrhoea morbidity and mortality and soil-transmitted helminths (Albonico *et al.* 2008; Cairncross *et al.* 2010). The 2008/2009 cholera outbreak in Zimbabwe, which had the Greater Harare accounting for more than 26% of the 4,300 reported cholera deaths, was linked to poor drinking water quality and exposure to sewage (World Bank 2013).

Harare province has the highest proportion of Zimbabwe's population that stood at 2.1 million people with a population density of 2,400 people per square kilometre

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according to the 2012 Zimbabwe census (ZIMSTAT 2012). Rapid urbanisation in Harare City has outpaced water and sanitation infrastructure development, and as a result, there are a huge number of people living without basic sanitation and safe drinking water (WHO/UNICEF 2006). The most affected areas include among others peri-urban settlements of Hopley, Hatcliffe Extension and Whitecliffe, which came up as a result of changes in land tenure after the year 2000 and the year 2005 clean-up exercise. (In 2005, the Government of Zimbabwe instructed councils to destroy all illegal settlements and unapproved extensions of buildings (Chirisa *et al.* 2014).)

Hopley Settlement has no adequate municipal water and sanitation services for individual households. Households rely on a limited number of municipal communal water standpipes, hand-dug shallow wells and a few boreholes for water supply while the sanitation option is mainly pit latrines. Thus, a threat of a repeat of a cholera outbreak still hangs in Harare, especially in areas with poor water and sanitation services. It is against this background that a study was carried out in Hopley Settlement located in the southern part of Harare during the period February to April 2015.

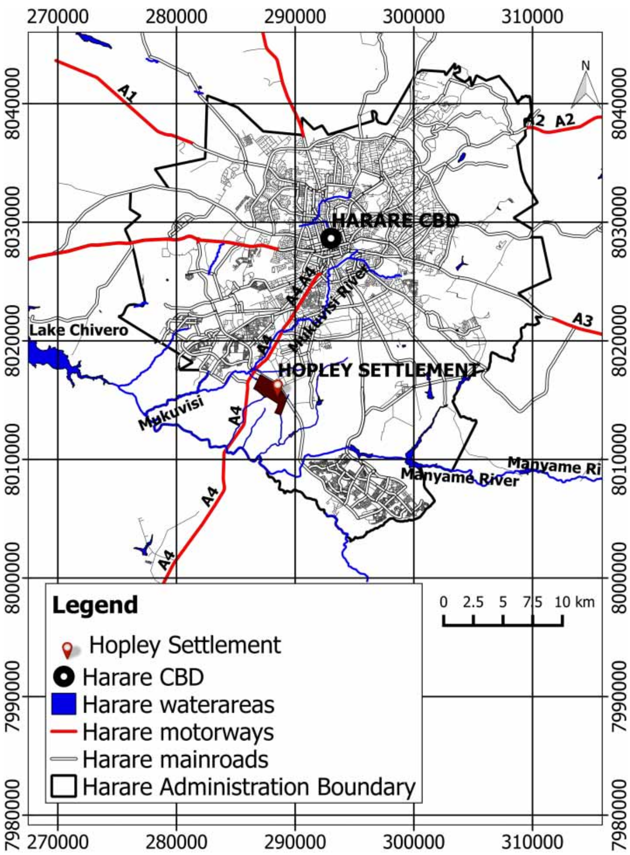

Figure 1 | Location of Hopley Settlement in Harare, Zimbabwe.

STUDY AREA

Hopley Settlement is located south of Harare's Central Business District (Figure 1) and has a population of about 15,000 (ZIMSTAT 2012). The study area occupies an area of about 4 km^2. According to the Southern Incorporated areas, Local Development Plan Number 31 for Harare, the housing structures are built on stand sizes of 100–150 m^2. The majority of houses in Hopley Settlement are temporary to semi-permanent shelters that range from plastic shacks to unapproved structures built with moulded and partially burnt earth bricks (Nyama 2013). A few houses have been built using approved plans and materials, and a large part of these structures was constructed by the then Ministry of Local Government and Urban Development (Nyama 2013).

Background on water supply and sanitation in Harare and Hopley

The problems of water and sanitation in Harare have been attributed to the rapid population growth, inadequate rehabilitation, and the maintenance of water and wastewater infrastructure, expensive technologies and the poor institutional framework (Nhapi 2009). Harare experiences huge water losses reported being around 60% (Ndunguru & Hoko 2016). This has resulted in erratic water supply and failure by the council to supply water regularly to all areas, with some areas not getting water over 10 years. These problems have led residents to resort to alternative sources including unsafe ones. The residents of Hopley have built structures on unserviced land; hence, development is taking place without adequate water and sanitation support infrastructure (Chirisa *et al.* 2014). The residents of Hopley Settlement rely on communal boreholes and standpipes that cannot meet the water demands; hence the use of shallow wells as an alternative source of drinking water.

The World Bank (2013) reported that the existing wastewater treatment facilities in the Greater Harare are not able to treat the existing volumes of wastewater generated.

Harare has not been able to expand the sewerage infrastructure, and the most affected areas in terms of infrastructure provision are peri-urban areas (McConville 2014). The main form of sanitation systems in Hopley are pit latrines that are often near to shallow wells (World Bank 2013). According to key informants in Hopley Settlement, the depth of the pit latrines ranges from 1.2 to 1.5 m. Most of the pit latrines are not lined, and there is no mechanism of desludging the filled up pits. UNICEF has supported the Hopley community with the construction of EcoSan toilets. However, residents of Hopley Settlement seem to prefer the use of pit latrines since the handling and final disposal of EcoSan toilet contents have often presented a great challenge (Musingafi *et al.* 2015). Some households in Hopley rely on septic tanks that are often poorly maintained or undersized (Nyatsanza & Chaminuka 2013).

MATERIALS AND METHODS

Study design

Selection of study area and sites

The peri-urban settlement of Hopley was selected as the study area as it is one of the largest peri-urban settlements with serious water supply and sanitation challenges with a potential to trigger another cholera outbreak in Harare. A total of 11 sampling sites were selected, and these included eight hand-dug wells (W1, W2, W3, W4, W5, W6, W7, and W8) and three boreholes (B1, B2, and B3). The average depth of the shallow wells in the settlement ranges from 0.5 m to 6 m, while boreholes were 35–40 m deep. The diameter of each well is about 1.2 m. The wellheads are not adequately protected in most cases and are only lined for 30 cm into the well.

Selection of study parameters

Chlorides and nitrates have been investigated as chemical indicators of groundwater contamination by latrines because of their high concentrations in excreta and their relative mobility in the subsurface (BGS 2002; Graham & Polizzotto 2013). According to BGS (2002), each person, on average, loses approximately 4 g of chloride per day through urine (90–95%), faeces (4–8%), and sweat (2%). Latrines have also been associated with increased well water turbidity (Dzwairo *et al.* 2006). According to Morris *et al.* (1994), dissolved oxygen (DO) concentration should be considered as a critical parameter in an investigation of groundwater contamination since it often controls the fate of dissolved organic contaminants by constraining the types and numbers of microorganisms present within a water source. Measurement of pH is one of the most important and most frequently used tests in determining water quality (WHO 2011). Electrical conductivity (EC) is affected by the presence of dissolved ions such as nitrates and chlorides in water which generally affect taste (Hoko 2008). Most of the ammonia in excreta is because of the breakdown of urea excreted in water (Jönsson *et al.* 2004). The presence of thermotolerant coliform (TTC) in drinking water indicates the presence of faecal material and that intestinal pathogen could be present (WHO 2011). Based on these and other facts reported in the literature, a total of eight parameters including pH, turbidity, DO, chloride, N-NO_3^-, EC, ammonia, and TTC were selected to determine the effect of pit latrines to subsurface (shallow wells) water quality.

The depth to the water table and lateral separation between onsite sanitation facilities and the groundwater source are some of the key parameters affecting groundwater pollution (Carroll *et al.* 2006). The level of contamination may also be influenced by the depth of the water source, and where hydraulic loads are high and exceed natural attenuation potential in the subsurface (Carroll *et al.* 2006). Researchers have identified a range of latrine siting guidelines from the varying transport distances observed for microbiological and chemical contaminants originating from pit latrines (Caldwell & Parr 1937). The Sphere Project (2011) suggests that the distance of latrines from water sources should be at least 30 m and the bottom of the pits should be at least 1.5 m above the groundwater table.

Methods of data collection

Water sampling and analytical techniques

A total of 44 ($N = 44$) water samples were collected from 11 sampling locations during four sampling campaigns launched during the period February 2015 to April 2015. The samples represented dry weather conditions for the duration of the study. The methods prescribed by APHA/AWWA/WEF (2005), i.e. *Standard Methods for the Examination of Water and Wastewater*, were used for the collection of water samples. Water samples were collected in 1-L acid rinsed and sterilised plastic bottles for chemical and microbial analyses, respectively. The samples were stored and transported to the laboratory in a cool box, and water samples were analysed within 24 h. A parameter such as pH, EC, DO, and turbidity was measured onsite immediately after sampling using field kits. The pH was determined using a pH ion meter pMx 3000. EC was measured using a WTW Cond. 340i test kit. DO was measured with an OXI 340i/set. Turbidity was measured using the HACH 2100N turbidity meter. TTC, chloride, N-NO_3^-, and ammonia were analysed in the laboratory according to *Standard Methods for the Examination of Water and Wastewater* (APHA/AWWA/WEF 2005). TTC was determined using the membrane filtration technique method 9222D with membrane lauryl sulphate broth culture media. Chlorides were analysed using the Silver Nitrate standard method 4500-CH-D. The ultraviolet spectrophotometric screening standard method 4500-NO_3^-B was used to measure N-NO_3^-. Ammonia was measured using the Photometric standard method 4500-NH_3 at a wavelength of 630–660 nm. A Solinist Model 101 Water Level Meter was used to measure the depth to water level from the ground surface during each sampling campaign.

Mapping of a pit latrine and latrine density assessment

The location of pit latrines in the study area was established using a GPS device and Google earth images of the settlement. The separation distances were based on the literature. Banks *et al.* (2002) suggested separation distances of 15–30 m as the minimum standard lateral distance between onsite sanitation facilities and water sources during disaster response. Wright *et al.* (2013) suggested separation distances of up to 100 m between the groundwater source and pit latrines. From this, radial distances of 15 m, 30 m, 50 m, and 100 m from the water point were considered for pit latrine density analysis in a Geographical Information System (GIS) environment.

Methods of data analysis and interpretation

Spatial variation of groundwater source contaminants

Spatial analysis was carried out in a GIS environment. In GIS, spatial interpolation of the groundwater points was applied using the Inverse Distance Weighting interpolation method to create raster surfaces for all the selected water parameters in this study (Nas 2009). Triangulated irregular network interpolation was used in GIS to create water-table contours for the selected groundwater points (Mitas & Mitasova 1999). The water-table contours were used to plot the direction of the groundwater flow as suggested by Mitas & Mitasova (1999).

Statistical data analysis

SPSS (v22) was used for all statistical analysis. Pearson's correlation test was done to determine the degree of association (positive or negative linear relationship) between the water quality results at each sampling point and the number of pit latrine densities in a radius of 15 m, 30 m, 50 m and 100 m (Wright *et al.* 2013). A critical value was determined for a 95% confidence interval from the sample size (N) and the Pearson Correlation Coefficient (r).

Student's t-test was used to determine groundwater quality suitability for drinking water requirements by comparing the mean values of the analysed groundwater parameters with the WHO drinking water guidelines and SAZ drinking water standards to show if there was any significant difference.

Principal component analysis (PCA) was used to determine major water quality parameters. PCA was used to reduce the complexity of the data sets and to ascribe concentration variations to significant processes leading to groundwater source contamination. The Kaiser Criterion of the Eigenvalue of the scree plot was used to extract the principal components of groundwater contamination (Bryant & Yarnold 1995).

RESULTS AND DISCUSSION

Groundwater quality

Tables 1 and 2 show the results of the mean levels and Student's t-test for the selected groundwater parameters.

Table 1 | Mean levels of selected groundwater parameters ($N = 44$)

Sampling point	TTC (cfu/100 mL sample)	Ammonia (mg/L)	Nitrates (mg/L)	Chlorides (mg/L)	EC (μS/cm)	DO (mg/L)	pH	Turbidity (NTU)
B1	0	0.04	27.9	144.7	1,011	2.1	6.68	31.0
B2	5	0.08	27.9	37.2	300	3.3	6.88	5.2
B3	9	0.08	13.2	42.5	313	3.8	7.13	1.1
W1	240	4.70	191.9	278.3	1,570	2.8	6.65	7.0
W2	153	0.46	271.2	173.7	968	4.2	6.15	3.1
W3	24	0.34	50.2	88.6	529	5.4	6.63	2.0
W4	19	0.04	59.2	31.9	250	3.5	6.13	1.3
W5	64	0.06	70.9	31.9	250	3.3	6.73	1.1
W6	155	0.02	68.6	46.1	268	4.1	6.38	2.3
W7	5	0.04	55.5	44.3	336	4.1	6.40	1.9
W8	223	0.10	47.7	75.2	531	4.2	6.65	1.3
Mean	82	0.54	80.4	90.40	575	3.70	6.58	5.2
WHO (2011)	0	<0.2	50	<300	400	–	6.5–8.5	<5
SAZ 560:1997	0	–	10	<250	700	>5	6.5–8.5	<1

'–' implies values not specified.

Table 2 | Summary of the Student's *t*-test results

	SAZ drinking water standards		WHO drinking water guidelines	
Parameter	Unacceptable (%)	Acceptable (%)	Unacceptable (%)	Acceptable (%)
pH	34	66	34	66
Turbidity	75	25	34	66
DO	36	64	–	–
Chlorides	9	91	0	100
Nitrates	98	2	50	50
EC	27	73	45	55
Ammonia	–	–	14	86
TTC	84	16	84	16
Average	**52**	**48**	**37**	**63**

'–' implies values not specified.

Table 3 shows the lateral distance of sampling points from the nearest pit latrine.

The colour schemes assigned (blue: acceptable value in drinking water in terms of SAZ (1997) drinking water standards; orange: acceptable value in drinking water in terms of the WHO (2011) drinking water guidelines; red: unacceptable value in drinking water in terms of SAZ (1997) and WHO (2011) drinking water standards/guidelines) to the spatial analysis of water parameters were to reflect the different bands or levels. The discussion for each parameter is presented below.

pH

The mean pH of all 44 samples ($N = 44$) was 6.6 and was acceptable according to the WHO (2011) guidelines and SAZ (1997) drinking water standards. The spatial variation in Figure 2 shows that only sampling points W2, W4, W6,

Table 3 | Lateral distance of the nearest pit latrine from groundwater points

Sampling point	B1	B2	B3	W1	W2	W3	W4	W5	W6	W7	W8
Nearest pit latrine distance	40.0	28.0	13.0	3.5	13.0	25.0	15.0	10.0	10.0	13.0	15.0

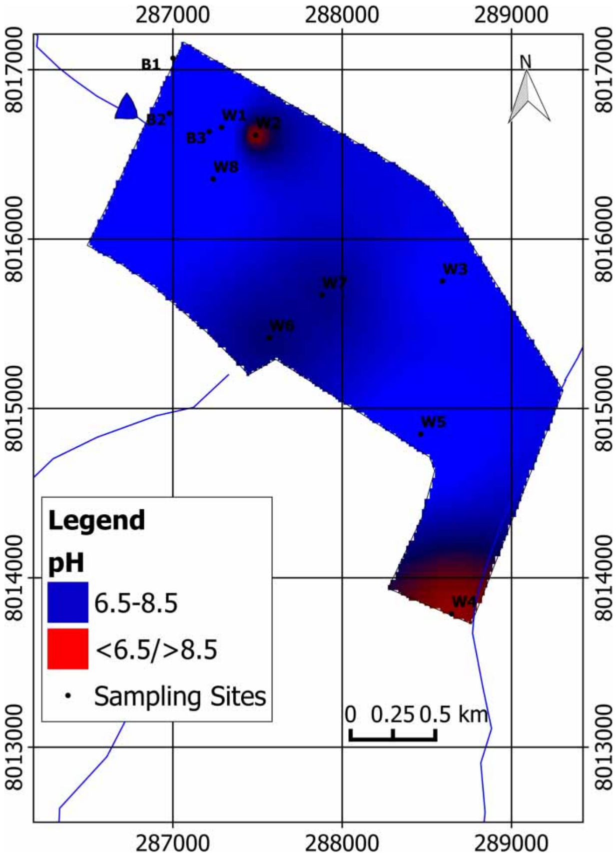

Figure 2 | Spatial distribution of pH for the period February to April 2015.

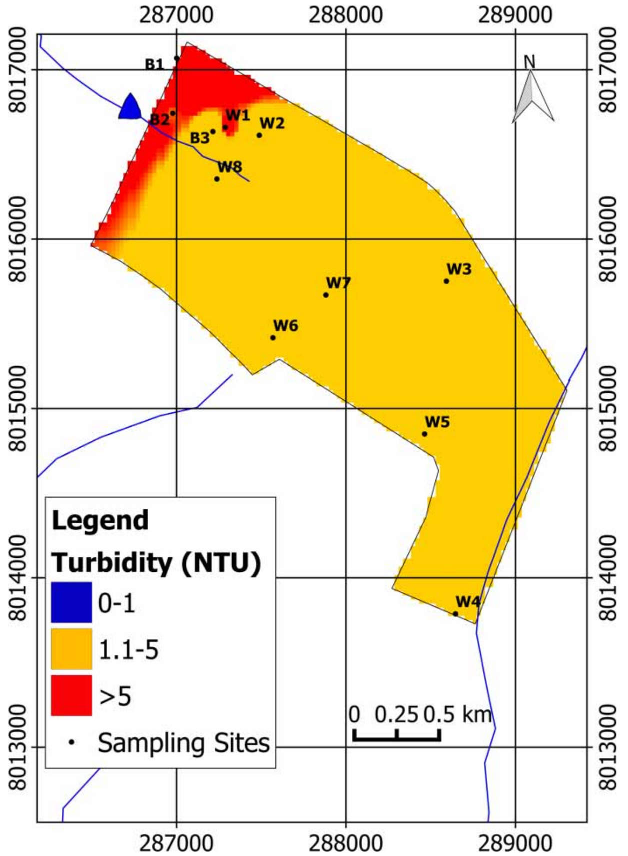

Figure 3 | Spatial distribution of turbidity for the period February to April 2015.

and W7 had mean concentrations (average of four samples) of 6.15, 6.13, 6.38, and 6.40, respectively, that were less than 6.5, and the lateral distance from the nearest pit latrine was 13.0 m, 15.0 m, 10.0 m, and 13.0 m, respectively. Considering all samples, 34% of all samples had pH levels unacceptable for drinking water (SAZ 1997; WHO 2011).

Turbidity

Levels of turbidity less than 5 NTUs were found only in samples B3, W2, W3, W4, W5, W6, W7, and W8 (WHO 2011). None of the samples met the recommended level of less than 1 NTU in terms of SAZ. The spatial variation in Figure 3 shows only that sampling points B1, B2, and W1 had mean concentrations (average four samples) that were unacceptable in drinking water (WHO 2011). There was evidence of collapsing internal walls for source W1; thus, silt, clay, and inorganic material affected the clarity of the water. Sample B1 had a reddish brown colour emanating from rusting borehole casing pipes. The acceptability of the water for drinking at water points B1 and W1 was reduced. The lateral distance of the water point from the nearest pit latrine had no effect on the turbidity levels found in the samples.

Dissolved oxygen

Only sampling point W3 had, on average of four samples, DO of 5.4 mg/L that was recommended in drinking water in terms of SAZ. The WHO (2011) drinking water guidelines do not have a specified value for DO. The spatial variation of DO is shown in Figure 4. The presence of organic material reduces levels of DO in water (WHO 2011).

Chloride

On average of four samples, the mean chloride concentration for all water points was within the permissible limits in terms of the WHO (2011) drinking water guidelines. Figure 5 shows the spatial distribution of chlorides. Only, water point W1 had a mean concentration of 278.3 mg/L above the recommended level of 250 mg/L (SAZ 1997). The lateral distance of the nearest pit latrine from the water point (W1) was 3.5 m that might suggest possible water contamination. Chloride concentrations in excess of 250 mg/L can give rise to detectable taste in water and hence the taste complaints of water that were highlighted by users for water point W1 (WHO 2011).

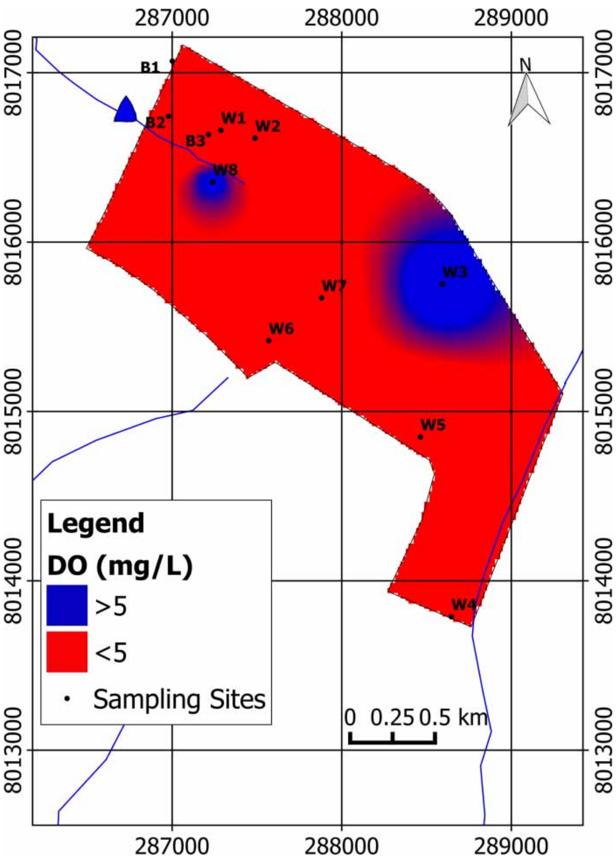

Figure 4 | Spatial distribution of DO for the period February to April 2015.

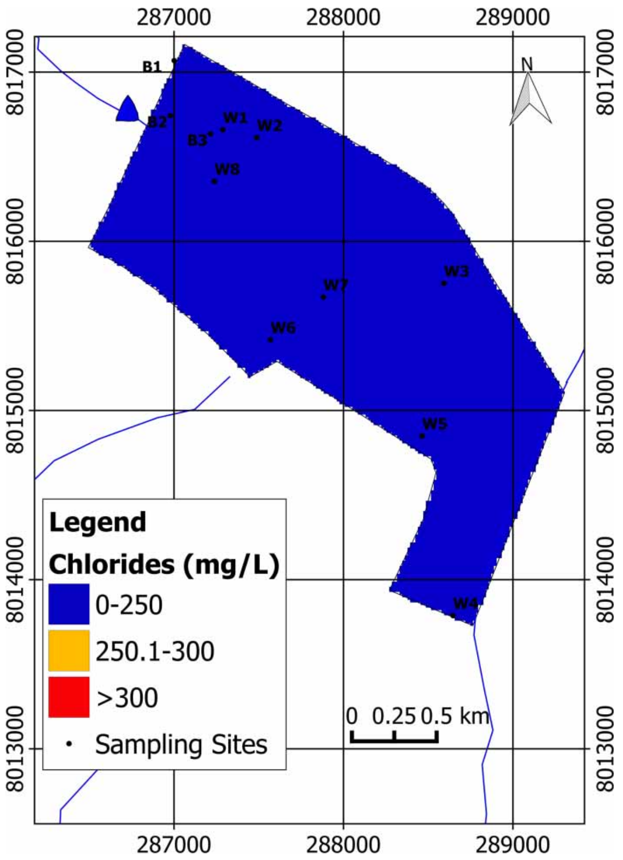

Figure 5 | Spatial distribution of chlorides for the period February to April 2015.

Nitrate

Only samples B1, B2, B3, and W8 had $N\text{-}NO_3^-$ that was safe in drinking water (WHO 2011), and the lateral distance of the water points from the nearest pit latrine was 40.0 m, 28.0 m, 13.0 m and 15 m, respectively. All the samples exceeded the recommended level of nitrate of 10 mg/L prescribed by SAZ (1997). Infants younger than 6 months old are susceptible to nitrate poisoning thereby generally making all the water points unsafe for drinking water (BGS 2002). Figure 6 shows the spatial variations for nitrates.

Electrical conductivity

Based on the WHO (2008) drinking water guidelines, only samples B1, W1, W2, W3, and W8 had EC at unacceptable mean levels in drinking water, while samples B1, W1, and W2 had levels unacceptable in drinking water in terms of SAZ. The WHO (2008) guideline is more stringent in the

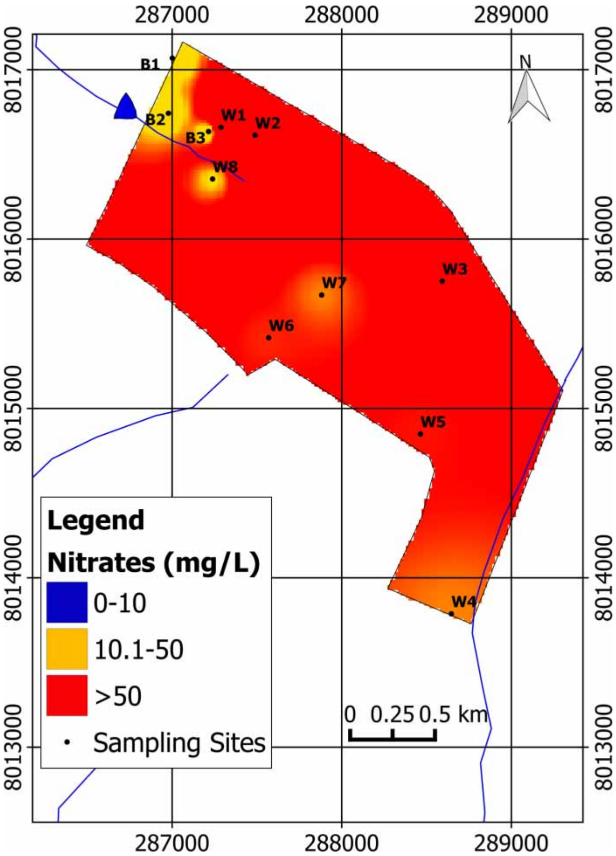

Figure 6 | Spatial distribution of nitrates for the period February to April 2015.

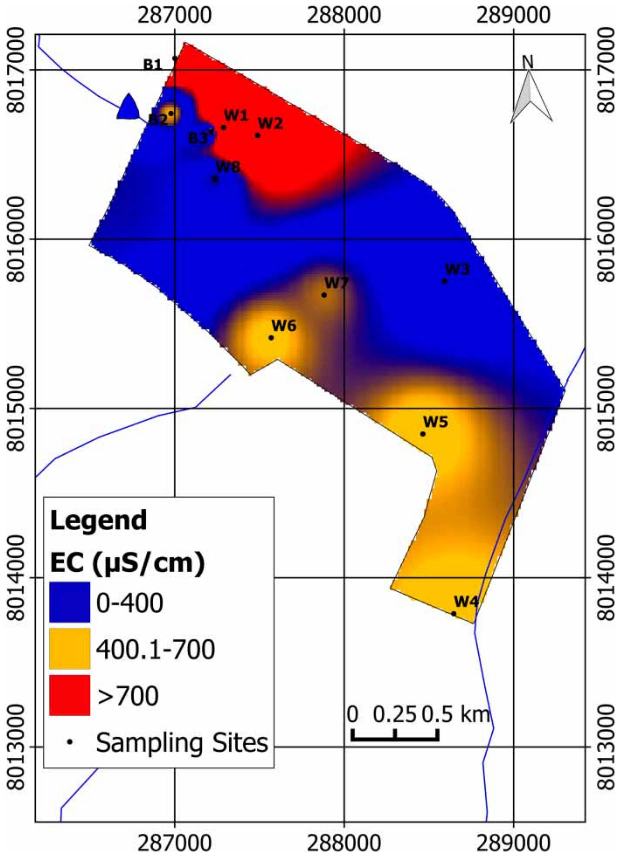

Figure 7 | Spatial distribution of EC for the period February to April 2015. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/washdev.2019.179.

EC limit in drinking water than the SAZ (1997) drinking water standard. Figure 7 shows the spatial variation for EC.

Ammonia

The mean value for ammonia (average four samples) for water samples W1, W2, and W3 exceeded the WHO (2011) guideline of 0.2 mg/L. SAZ (1997) drinking water standards do not have a specified value for ammonia. The spatial distribution for ammonia is shown in Figure 8. The relatively short distance of 3.5 m and 13.0 m of the nearest pit latrine to W1 and W2, respectively, and the direction of the groundwater flow shown in Figure 9 might account for the relatively high concentration levels for ammonia at the water points.

Thermotolerant coliforms

The results showed a mean ($N = 44$) TTC count of 82 cfu/100 mL that was greater than the permissible count of 0 cfu/100 mL in drinking water. On average of four samples, only water point B1 had TTC levels of 0 cfu/100 mL. Figure 10 shows the spatial distribution of TTC. The colour schemes assigned (blue: 0 cfu/100 mL (no risk areas); orange: 1–100 cfu/100 mL (low to intermediate risk areas); red: $>$100 cfu/100 mL (high to very high risk areas)) were to reflect the different levels in the spatial distribution of TTC on the water points studied based on WHO (1997) segregation for risks to pathogenic contamination of drinking water.

Water points B1, B2 and W7 had a spatial distribution that suggested no risk to water contamination by pathogenic organisms. Water points B3, W3, and W5 had a spatial distribution of TTC that suggests low to intermediate risk. Levels above 100 cfu/100 mL were found at water points W1, W2, W6, and W8, thereby putting these sources at high to very high risk to water contamination by pathogenic organisms harmful to human health (WHO 1997).

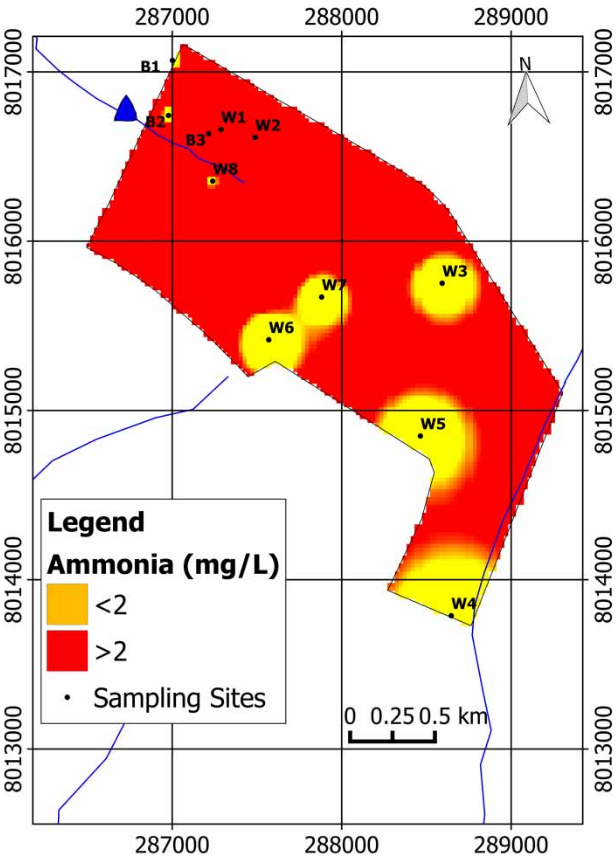

Figure 8 | Spatial distribution of ammonia for the period February to April 2015.

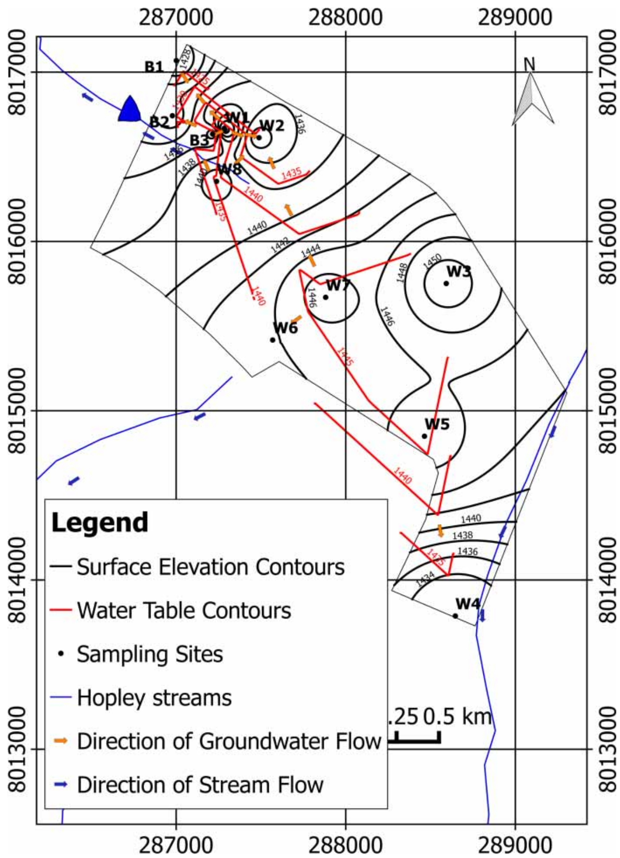

Figure 9 | Groundwater flow direction in Hopley Settlement.

It was generally observed that shallow wells at W1 and W2 were not safe for drinking water since they had five out of eight parameters not meeting the recommended levels. Water points W3, W4, W6, and W7 had four out of the eight parameters that were at levels not safe in drinking water. The short lateral distance of the water points from the nearest pit latrine strongly suggests the poor water quality at these wells. However, water points W5 and W8 had better quality, i.e. three out of eight parameters at levels not safe in drinking water, and the water quality was not affected by the short lateral distance of 10 m and 15 m from the nearest pit latrine. Boreholes B1 and B2 also had three out of the eight parameters at levels not recommended in drinking water. Borehole B3 had the best water quality with only two out of eight parameters at levels unacceptable in drinking water. All samples, except B1, were contaminated with TTC, while seven out of the 11 sampling points had nitrates at levels unsafe in drinking water in terms of the WHO guidelines. The expectation will be a decrease in water quality in wet weather conditions. Therefore, nitrates posed an immediate health risk to consumers. The results also suggest the risk of groundwater contamination by pathogenic organisms due to elevated TTC counts in the water samples.

Determination of key parameters

The data were tested for suitability for PCA through the correlation matrix and Bartlett's test of sphericity. Table 4 shows the Kaiser–Meyer–Olkin (KMO) Measure of Sampling Adequacy. The data were considered suitable for

Table 4 | Sampling adequacy using KMO and Bartlett's test

KMO Measure of Sampling Adequacy		**0.612**
Bartlett's test of sphericity	Approx. chi-square	213.465
	df	28
	Sig.	0.000

Table 5 | Correlation coefficients of groundwater parameters

	TTC	Ammonia	Nitrates	Chlorides	EC	pH	DO	Turbidity
TTC	1.000	0.246	0.471	0.367	0.373	0.026	0.076	−0.141
Ammonia	0.246	1.000	0.578	0.549	0.613	0.196	−0.201	0.122
Nitrates	0.471	0.578	1.000	0.558	0.574	−0.170	0.038	−0.045
Chlorides	0.367	0.549	0.558	1.000	0.959	−0.118	−0.213	0.354
EC	0.373	0.613	0.574	0.959	1.000	−0.044	−0.312	0.477
pH	0.026	0.196	−0.170	−0.118	−0.044	1.000	−0.121	0.051
DO	0.076	−0.201	0.038	−0.213	−0.312	−0.121	1.000	−0.550
Turbidity	−0.141	0.122	−0.045	0.354	0.477	.051	−0.550	1.000

PCA since the KMO value (0.612) obtained was greater than 0.6 and Bartlett's test of sphericity value (0.000) was less than 0.05. Retained items had correlation coefficients of above 0.3. Any correlation coefficients less than 0.3 and Bartlett's test above 0.05 were not used as suggested by Mustapha *et al.* (2012).

Table 5 shows the correlation matrix (SPSS output) used to select component suitability for PCA. Items retained included TTCs, nitrates, chlorides, EC, ammonia, and turbidity that had correlation coefficients of above 0.3. The excluded items included pH and DO.

The result of PCA in Table 6 shows that of the eight components, only three were extracted based on Chatfield & Collin's (1980) assumption that components with an eigenvalue of less than 1 should be eliminated. The extracted three components were rotated according to the varimax rotation in order to make interpretation easier (Table 7). Based on the component loadings, the variables were grouped accordingly with their designated components as follows:

Component 1: Nitrates, EC, chlorides, ammonia, and TTC

Component 2: Turbidity and DO

Component 3: pH

Components 1, 2, and 3 explained 41.7%, 21.4%, and 13.8% of the variance, respectively. The three extracted components when added account for 76.9% (that is their cumulative variance) of the total variance of the observed variable. Also based on the scree plot shown in Figure 11, three components that had an eigenvalue greater than 1 were extracted. Therefore, the key parameters in groundwater contamination were nitrates, EC, chlorides, ammonia, and TTC that accounted for 41.7% of the total variance.

Table 6 | Principal component matrix (three components extracted)

	Components		
Variables	1	2	3
TTC	0.484	0.516	0.187
Ammonia	0.744	0.076	0.360
Nitrates	0.722	0.477	−0.038
Chlorides	0.910	0.005	−0.166
EC	0.954	−0.097	−0.098
pH	−0.022	−0.250	0.932
DO	−0.343	0.739	−0.035
Turbidity	0.409	−0.771	−0.186

Table 7 | Rotated component loading matrix, eigenvalues, total variance and cumulative variance

	Components		
Variables	1	2	3
Nitrates	0.845		
Electrical conductivity	0.826		
Chlorides	0.820		
Ammonia	0.744		
Thermotolerant coliforms	0.663		
Turbidity		0.889	
Dissolved oxygen		−0.798	
pH			0.962
Eigenvalue	3.334	1.712	1.108
Total variance %	41.676	21.398	13.845
Cumulative variance %	41.676	63.074	76.919

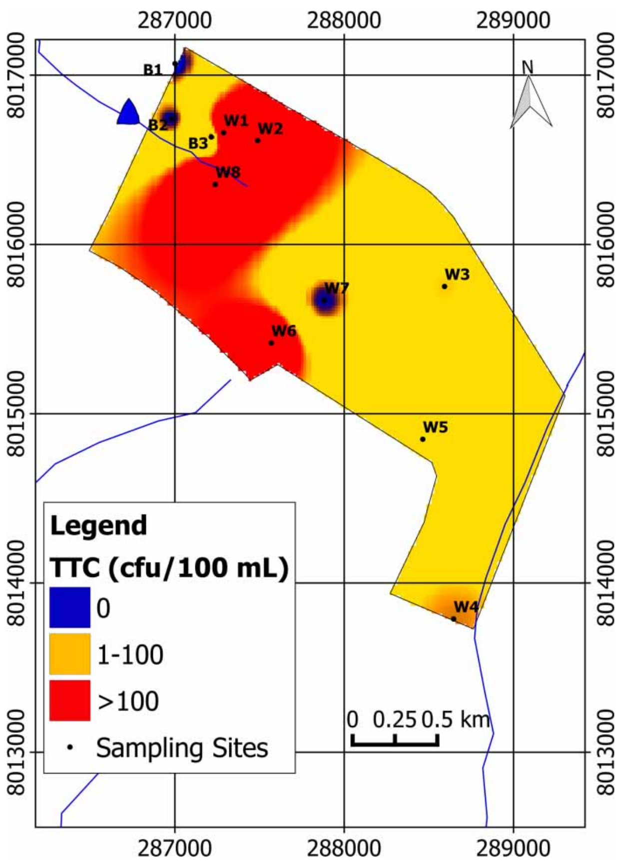

Figure 10 | Spatial distribution of faecal coliform contamination. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/washdev.2019.179.

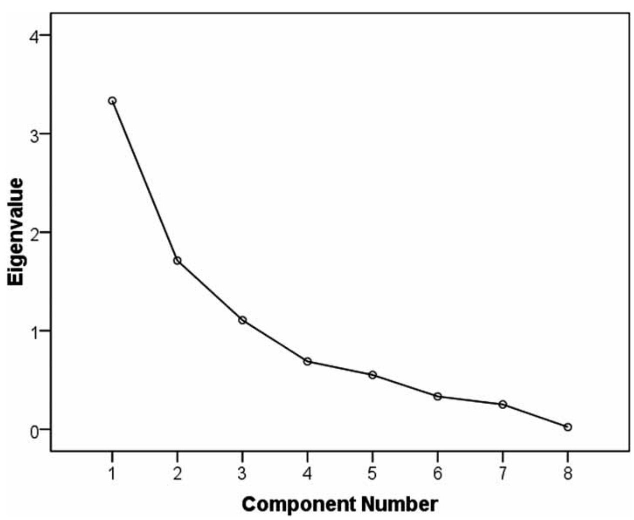

Figure 11 | Scree plot of the eigenvalue of observed components.

Table 8 | Pit latrine density around the sampled points

	Number of pit latrines			
Sampling point	**15 m radius**	**30 m radius**	**50 m radius**	**100 m radius**
B1	0	0	0	3
B2	0	5	13	54
B3	0	3	5	44
W1	5	8	21	63
W2	1	3	13	49
W3	1	1	3	11
W4	0	3	5	24
W5	0	4	6	29
W6	0	3	8	43
W7	0	4	8	19
W8	1	4	13	61

Impact of pit latrine density on groundwater quality

Table 8 shows the results of the cumulative number of pit latrines in each radius for the groundwater sampling points. The highest pit latrine density in the 15 m, 30 m, 50 m, and 100 m radius was 5, 8, 21, and 63, respectively. There was no significant increase in pit latrine density from 15 m to 30 m radius, i.e. five to eight pit latrines. Well W1 had the highest pit latrine density of 63 pit latrines in a 100 m radius.

The pit latrine density was correlated with groundwater levels of pH, turbidity, DO, chlorides, nitrates, EC, ammonia, and TTC (Table 9). The results show that an increase in the number of pit latrines from 15 m to 100 m radius from the groundwater point showed a strong positive linear correlation with levels of nitrate, TTC, ammonia, chloride, and EC, while turbidity had an inverse relationship. DO and pH showed no relationship with increasing pit latrine density. Nitrate, TTC, ammonia, chloride, and EC were related to an increase in pit latrine density. The results showed that there was a strong association of nitrate, TTC, ammonia, chloride, and EC levels to high pit latrine density that suggested groundwater contamination by pit latrines.

CONCLUSIONS AND RECOMMENDATIONS

The results show that, on average, 63% of all the groundwater samples were acceptable for drinking water in

Table 9 | Relationships of groundwater parameters and pit latrine densities ($N = 44$)

	Nitrate	Ammonia	TTC	Chlorides	DO	pH	EC	Turbidity
Density 15	0.522**	0.684**	0.425**	0.843**	−0.163	−0.005	0.813**	0.026
	0.000	0.000	0.004	0.000	0.290	0.976	0.00	0.867
Density 30	0.304*	0.438**	0.413**	0.256	−0.233	0.074	0.214	−0.370*
	0.051	0.003	0.006	0.103	0.128	0.633	0.164	0.013
Density 50	0.528**	0.487**	0.562**	0.508**	−0.069	−0.047	0.508**	−0.326*
	0.000	0.001	0.000	0.000	0.656	0.760	0.000	0.031
Density 100	0.525**	0.354*	0.654**	0.323*	0.035	0.045	0.292	−0.376*
	0.001	0.032	0.000	0.012	0.822	0.773	0.055	0.012

**Correlation is significant at the 0.01 level (two-tailed).
*Correlation is significant at the 0.05 level (two-tailed).

terms of the WHO drinking water guidelines, while 48% were acceptable for drinking water in terms of SAZ drinking water standards. Groundwater sources were more susceptible to contamination by TTC since they contributed to 84% of the water samples exceeding the recommended levels in drinking water in terms of both reference documents. The key parameters to groundwater contamination were nitrates, EC, chlorides, ammonia, and TTC that accounted for 41.7% of the total cumulative variance of 76.9% from key components. There was a strong association of nitrate, EC, chloride, ammonia, and TTC levels to increasing pit latrine density that suggested groundwater contamination by pit latrines. It is recommended that the community adopts the point-of-use treatment of drinking water.

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