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Assessment of the Impact of Pit Latrines on Groundwater in the Melen Slum, Cameroon

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ABSTRACT

This study is aim at determining the minimal distance needed between pit latrines and groundwater, to analyze the pit latrines density map in the Melen slum. To this end, several research tools including questionnaires, sample collection, laboratory analysis, global position system survey, linear model predictions and map design. In this study, questionnaires were used to understand people's views on groundwater management and environmental sanitation. The preliminary survey showed that 74% of the respondents use pit latrines to treat wastewater, 23% successfully establish septic tanks, and 3% still did not have sanitary facilities. The survey also showed that respondents believed that water contamination is a serious problem and therefore needed pretreatment. According to the quality and turbidity of well water, 7% of households report to treat well water with bleach, 20% claim to put a few drops of bleach into the bucket before using it as drinking water, and the rest claim to drink it without pretreatment. Nineteen water wells in the Melen slum were analyzed and the characteristics of these samples were explained by a simple linear regression model. It was concluded that the minimum distance between sanitation facilities and water intake was 42.89 ± 16.76 m. Using the density analysis tool in ArcGIS software, the groundwater pollution map is designed according to the on-site sanitary coordinates and the calculated minimum distance. This map shows that more than 97% of the groundwater is infected. Then strong measures are taken to ensure that every building is equipped with improved sanitation as the septic system.

Keywords: Pit latrines, Groundwater, Minimal distance, Linear regression, Melen slum

INTRODUCTION

Access to water and sanitation is crucial due to its significant impacts on health, time, dignity and economic losses. Every year, approximately 1.4 million peoples die worldwide due to diarrhea from waterborne diseases [1]. Women and girls are particularly affected by a lack of access to water and sanitation services [2,3]. Safe drinking water and adequate sanitation are a human right. However, the challenges related to water, sanitation and hygiene are enormous. More than 748 million people (more than 90 per cent in rural areas) lack improved sources of drinking water, and even 2.5 billion people (70 per cent in rural areas) do not have full access to improved sanitation, of which 1 billion continue to use open defecation [4]. The majority of this burden falls upon individuals World Health Organization reside in developing countries [5]. Thus, the United Nations (UN) declares access to water and sanitation a fundamental human right [6], and individuals and communities in developing

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countries cannot maintain health and achieve the millennium development goals without access to water and sanitation [7,8].

Providing people with quality water and acceptable sanitation is a major challenge due, inter alia, to unplanned urbanization and water shortages [9,10]. The Rapid growth of cities has seriously exceeded the ability of most cities to provide adequate water and sanitation services to their citizens [11]. Water use has increased dramatically over the past 50 years due to population growth, urbanization and increased demand for agricultural irrigation [12]. Another gap identified is the impact on the sustainability of community water and sanitation programs, which are often threatened by many attitudes, institutions, infrastructure and economic factors [13].

Many water and sanitation projects in developing countries are unsustainable due to financial costs, lack of community ownership of water and sanitation infrastructure, lack of community attitude and behavior towards health education, and community participation [14]. Other challenges associated with WASH services include lack of investment in community-based and small-scale approaches [15,16] lack of reliable information (critical gap in monitoring system), weak national capacity to implement plans, insufficient funding and the most recent gap is concentrated on the gap in access to water and sanitation at the global and regional levels [17]. WASH is emerging and complex public health challenges facing communities in developing countries. Cameroon is experiencing faced the challenge of groundwater quality [18]. Therefore, groundwater pollution is an important problem because it is increasingly used for human needs. The High concentration of fecal pollutants in groundwater is a considerable health problem [19,20]. A field survey is conducted on the outskirts of Yaoundé with the aim of calculating the required distances through statistical analysis and prediction models between a well and pit latrines, verifying the respect of this distance onsite, assessing whether the current decentralized water treatment practices adopted by the population are sufficient to deal with the threat of fecal pollution, and exploring potential correlations between fecal contamination markers in groundwater with spatially distributed variables such as well or pit latrines density so as to be able.

GEOGRAPHICAL SETTING

The town of Yaoundé is located between latitudes 3° North and 5° and longitudes 11° at 12° East and is divided into seven Divisions, Yaoundé I-VII. The Melen spontaneous settlement is situated in Yaoundé VI and is part of the watershed of Abiergue. This zone is divided into five quarters: Melen VI, Melen VII-A, Melen VII-B, Melen IX and Nkolbikok II (**Figure 1**). There are about 15000 residents in the area, with an average of 6 per household.

The climate here is the typical equatorial type with 4 seasons, the mean precipitation is 1600 mm/year, the daily mean temperature is 24°C [22]. There are two rainy seasons (a long and a short period) from August to November and from March to May respectively. Two dry seasons as well running from December to February and from June to August.

Hydro-geologically and hydrographically, Yaoundé is in a crystalline environment, and meteorological records show that Yaoundé's environment is conducive to the recharge of groundwater level rather than the surface water flow of the basin [22]. The main drainage of the study area is Edzoa-Mballa River, which takes its source at Melen VII-A and then flows out of zone into Abiergue River **(Figure 1).**

Yaoundé soils are primarily composed of Precambrian deposits of metamorphic rocks, namely gneiss, mica, migmatites, and schists. Red ferrallitic soil dominates most of the area [23]. However, as deep as ten meters, this soil is leached by silica and percolating water, making it only marginally productive for agriculture.

The zone is characterized mostly by spontaneous constructions and unplanned urbanization, with a small organized portion homing well-to-do family [24]. This situation makes the area inaccessible by vehicles except for Melen VII-B and Nkolbikok-II, making impossible the collect of household waste by the company in charge of hygiene and health. This explains the accumulation of waste throughout the city and even in the vicinity of rivers.

Anthropogenic activities are very prominent in this zone as the local population strive to earn a living. These activities are of interest because they directly or indirectly have an impact on water sources, mostly through contamination of groundwater. Human activities like animal rearing (poultry, piggery, goat and sheep rearing), small commerce, garage mechanics, farming, hairdressing, brick fabric and constructions generate waste that is washed or transported mostly by rainwater, infiltrate into the ground, and contaminate groundwater [21].

The region has a wide range of social classes, from affluent families to low-income families, which affects access to adequate water and sanitation. According to the previous report of the National Institute of statistics on the region in 2011, the national water supply company provides high-quality water to 25% of the population, and the remaining 75% buy water or use wells. The company's insufficient capacity led to intermittent water supply and flooding of wells in the area. Health conditions vary because there are no centralized health systems in the region. Hence, human excrements, urine and flush water flow out pit latrines, water channel or along the road as black liquids. This situation can create contamination of nearby wells distributed as illustrated in **Figure 2**. Clay and laterite present a very low permeability, which implies that the upper geological units provide some protection against contamination associated with the infiltration of surface run off [22]. However, since domestic wells and pit latrines often pass through these impermeable layers, it is expected that the pollution caused by the lateral flow of groundwater will still exist. Even if this is not done, the sandy lens embedded in the clay matrix is permeable. This means that drinking wells and pit latrines can be contacted through them.

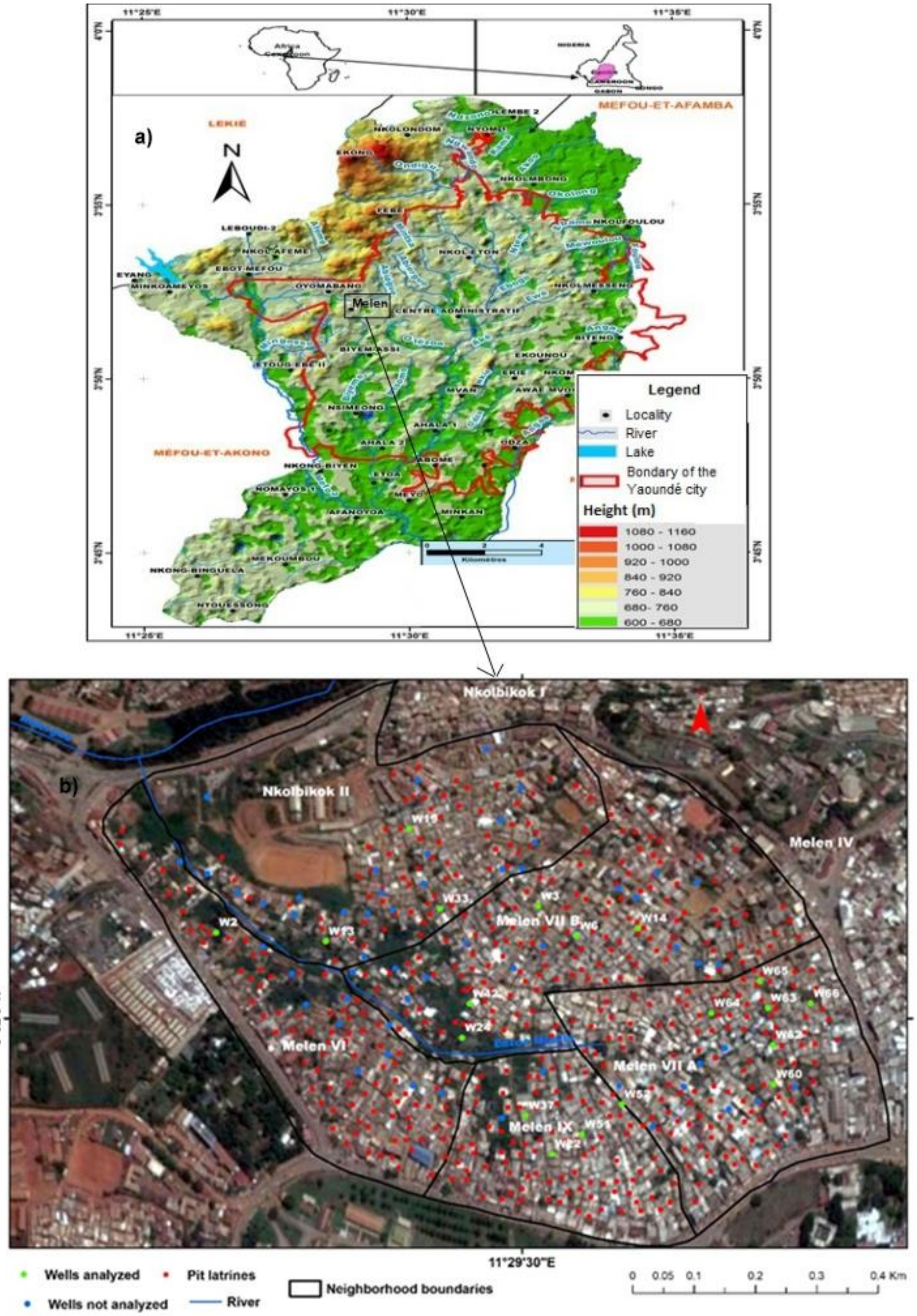

Figure 1. Study area (a) and location of Yaounde (b) in the Melen Slum.

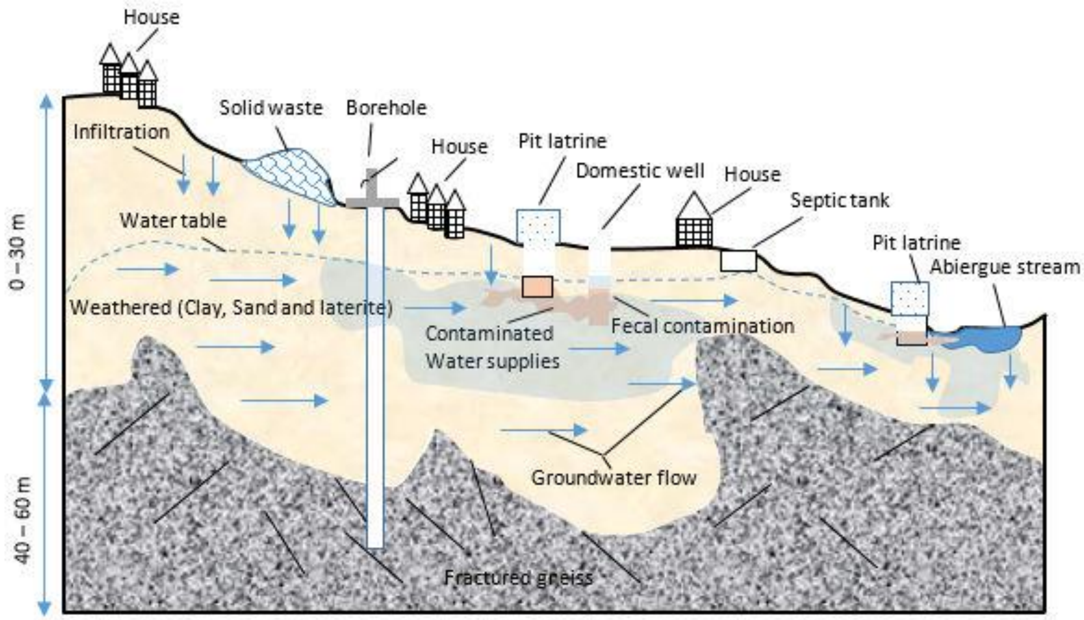

Figure 2. Synthetic diagram of the dynamics of pollution of groundwater in Melen slum.

MATERIALS AND METHODS

A preliminary assessment of the study area was carried out in dry season (December 2016 and January 2017). On these occasions, a questionnaire survey was conducted on 200 randomly selected families. The main objective is to determine people's understanding of the interaction between on-site sanitation and household water supply. As shown in **Table 1**, the survey form includes open-ended and closed-ended questions. A GPS unit of Garmin brand is used to obtain the geographical coordinates of pit latrines and wells.

Table 1. Observation questionnaire used for sanitary risk inspection of groundwater sources.

Questions	Supplementary information	Additional information
How many people inhabit the household? What is your major source of drinking water?	Is the well protected? If so, how? Is the protection scheme damaged?	Well and pit latrines coordinates Topographic location of well and pit latrines
Do they drink water from the well?	Was the well during the visit?	Static level of water
Do you treat your well before using its water for drinking? If so, how often?	Can excess wastewater accumulate around the well?	Photograph of the well Photograph of the pit latrine
Do they own a pit latrine? If so, where is it located and why?	Were there contamination sources around the well? If so, which ones?	Turbidity *analysis* Phosphate *analysis*
What type of toilet do you use? What is the distance between the nearest well and your pit latrines?	Could household members produce a sample of the product they use to treat drinking water?	Nitrate *analysis* Total coliform *analysis*
What was the last time a member of your family lastly suffered from a water disease?	If there is a pit latrine, what kind of pit latrines is it?	Fecal coliform *analysis* *E. coli analysis*

However, due to the reluctance and lack of information of the populations, some answers were not obtained. Nevertheless, the database is sufficient to draw conclusive results in the analysis process.

A total of nineteen wells were sampled. Selection of sampling stations near pit latrines was done. The stations were sampled during January 2017. The water samples were collected into clean 500 ml plastic bottles, after cleaning using 0.1m $HN0_3$ (aq) and thereafter-rinsing three times with the water to be sampled. Samples were collected by lowering a weighted bottle (bottle with weights inside to facilitate sinking) down to the water level.

The analysis of the nineteen samples were made in the lab of the University of Yaoundé I. The analysis parameters are turbidity, nitrate, phosphate, Total Coliform (TC), Fecal Coliform (FC) and *Escherichia coli* (*E. coli*).

MS Excel was used to describe the data set. Based on ArcGIS software, the minimum distance between pit latrines and domestic wells is determined by simple regression method.

Simple linear regression is a technique for the analyzing the response variable x defined in equation 1 (Eq. 1):

$$y = ax + b \tag{1}$$

The parameters a and b are computed using the formulas (Eq_s. 2 and 3):

$$b = \sum_{i=1}^{n} \frac{(x_i - \overline{x})(y_i - \overline{y})}{(x_i - \overline{y})^2} \tag{2}$$

$$a = \overline{y} - b\overline{x} \tag{3}$$

where $\overline{x}$ and $\overline{y}$ are the mean value of x and y.

The mean square error (MSE) which represents how far data will fall from the regression predictions on the scale of the outcome measurements is (Eq. 4).

$$MSE = \frac{\sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)^2}{\left(x_i - \overline{x}\right)^2} \tag{4}$$

where $\hat{y}_i$ is the predicted value of y_i

The R^2 value or multiple coefficients of determination is equal to the square of the simple correlation of x and y in simple regression. In either case, R^2 can be interpreted as the fraction of the total variation in the outcome that is accounted for by regressing the outcome on the explanatory variable and given by this equation (Eq. 5).

$$R^2 = \frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{\sqrt{\left[n\sum x^2 - \left(\sum x\right)^2\right]\left[n\sum y^2 - \left(\sum y\right)^2\right]}} \tag{5}$$

So R^2 is the portion of the total variation in Y that is explained away by using the x information in a regression. R^2 is always between 0 and 1.

The minimal distance needed between sanitation is the minimal distance needed so that the water characteristic will meet the standard of drinking water.

So, it's the minimum the needed distance for water characteristics (turbidity, nitrate, phosphate, total coliforms, fecal coliforms and *E-coli*). Then we will have to predict thanks to the simple linear method, the minimum distances needed for each characteristic to meet the standard.

The minimal distance needed between sanitation and well will then be minimum of the distances obtained from each characteristic with an acceptable correlation.

By using GPS coordinates of wells and sanitation, the number and proportion of the recorded wells which are affected will be determined. These affected wells are those which are bore in a distance smaller than minimal distance needed.

Thematic map representing the density of those infected wells and pit latrines (PL) are produced on ArcGIS software to visualize the emergence of the situation of groundwater in the study area. This density is expressed by equation 6 [25,19].

$$PL_{density} = \frac{1}{r_{assess}^2 \pi} \sum_{r_{PL}=0}^{r_{PL} < r_{assess}} n_{PL} \tag{6}$$

Where, n_{PL} is the number of pit latrines with a distance to the wells r_{PL} within a radial area of assessment with a radius r_{assess} [unit: Pit latrines number PL/ (Length L)^2].

Whilst providing a metric of the overall number of pit latrines surrounding the borehole, the impact of pit latrines very close to a well that may pose a higher risk to the water quality may become obscured by the averaging over the larger radial area used [19].

RESULTS

Assessment results are directly representing of the living conditions of about 200 people. 98% of the respondents were women because men were outdoor during the survey. **Figure 3** shows examples of some typical wells in the study area. On-site inspection showed that only 5% of household wells were protected in the form of apron and concrete well cover, and 95% of wells were not protected at all. Only 37% reported using water from improved sources as drinking water and 63% habitually used water from household wells as drinking water for everything else. Reasons for not drinking well water included health issues (19%), unpleasant taste (32%), presence of an improved water source nearby (27%), turbidity (15%), presence of obvious contaminant sources (4%) and other considerations (3%).

Figure 3. Examples of the most common groundwater extraction devices and structures in the Melen Slum: (A) limited protection well; (B) Protected well with lid in poor condition (limited protection); (C) Unprotected well; (D) Protected well with no lid (limited protection).

There are many groundwater pollution sources in Melen community of Yaoundé, which are as diverse as human activities. In terms of site sanitation, the following activities that may pollute groundwater were identified: poorly designed pit latrines and solid and liquid waste disposal. Groundwater pollution also results from poor site selection and design of groundwater supply infrastructure and excessive exploitation of groundwater due to the inability of national water company to provide drinking water to these residents.

Respondents believe that water pollution is a serious problem. 7% of households reported that they treat well water with bleach, which is only done once or twice a year, depending on the turbidity of the water. 20% of households reported dropping a few drops of bleach in the water before drinking. The remaining families reported that they consumed water from wells without prior treatment.

Pit latrines are the most widely used on-site system (74%), second only to septic tanks (23%), but some families still do not have sanitation facilities and use outdoor defecation (3%). The field survey provides some valuable data for people to choose the location of pit latrines. About 4% of the respondents said that they chose the location of the pit latrines to stay away from the well, while 30% said that the pit latrines were located downstream of the well to prevent water pollution. 52% of households gave reasons, including distance from house (40%) and land availability (12%). About 14% of households did not give any reason, and these results showed that most households did not establish a relationship between pit latrine and well pollution.

For parameters such as turbidity, nitrate, Total Coliforms (TC), Fecal Coliforms (FC) and *E-coli*, the results of all (19) sampling points are listed in **Table 2**. The turbidity ranged from 3.52 to 28.83 NTU with an average of 10.59 ± 7.00 NTU (**Table 3**). **Figure 4a** shows the relationship between the nearest pit latrines and the turbidity of the sampled wells. The equation of the regression line is y = -0.0926x + 12.735. Turbidity shall be less than or equal to 5 NTU; when y = 5 NTU, x is 85.58 m, and the minimum distance between pit latrines and wells is D_1 = 83.58 m, while R^2 = 0.0374, which means that only 3.74% of the turbidity value depends on the distance from the well. Therefore, D_1 is not used because the significance of simple linear regression is too low. This significant turbidity level can be interpreted as that turbidity mainly depends on the quality and maintenance of the wells which is very random.

Table 2. Water quality analysis results.

Wells N°	d(m)	Total coliform (cfu/100ml)	Fecal coliform (cfu/100ml)	*E. coli* (cfu/100ml)	Turbidity (NTU)	Nitrate (mg/l)	Phosphate (mg/l)	Cover type
W3	41	0	0	0	9.44	3.2	0	Timber
W6	15	98	120	17	5.55	13.05	0.47	Concrete
W66	16	117	80	21	15.8	13.4	0.48	Timber
W51	9	120	170	37.5	7.75	11.9	0.52	Timber
W62	12	200	90	23	20.87	8.1	0.41	Timber
W52	17	156	81	14.6	23.99	9.17	0.81	Steel
W65	12	176	75	30	11.53	10.89	0.7	Timber
W64	14	60	74	21	28.83	5.42	0.82	Concrete
W60	25	76	64	14	3.52	8.44	0.4	Concrete
W13	21	88	92	29	8.82	13.59	0.26	Cars tyres
W37	50	0	0	3	7.02	2.3	0.07	Concrete
W2	14	155	186	59	5.28	11.4	0.45	Timber
W22	43	1	0	0	8.8	1.6	0.09	Concrete
W19	59	0	0	0	10.56	1	0.01	Concrete
W24	25	240	49	11	7.04	7.4	0.29	Concrete
W42	25	98	100	23	3.52	2	0.33	Concrete
W63	13	100	118	17	5.28	2.6	0.8	Concrete
W33	21	120	20	20	10.56	10.5	0.12	Timber
W14	8	157	102	36	7.04	12.1	0.59	Timber
Where d is the distance to the nearest well to pit latrine								

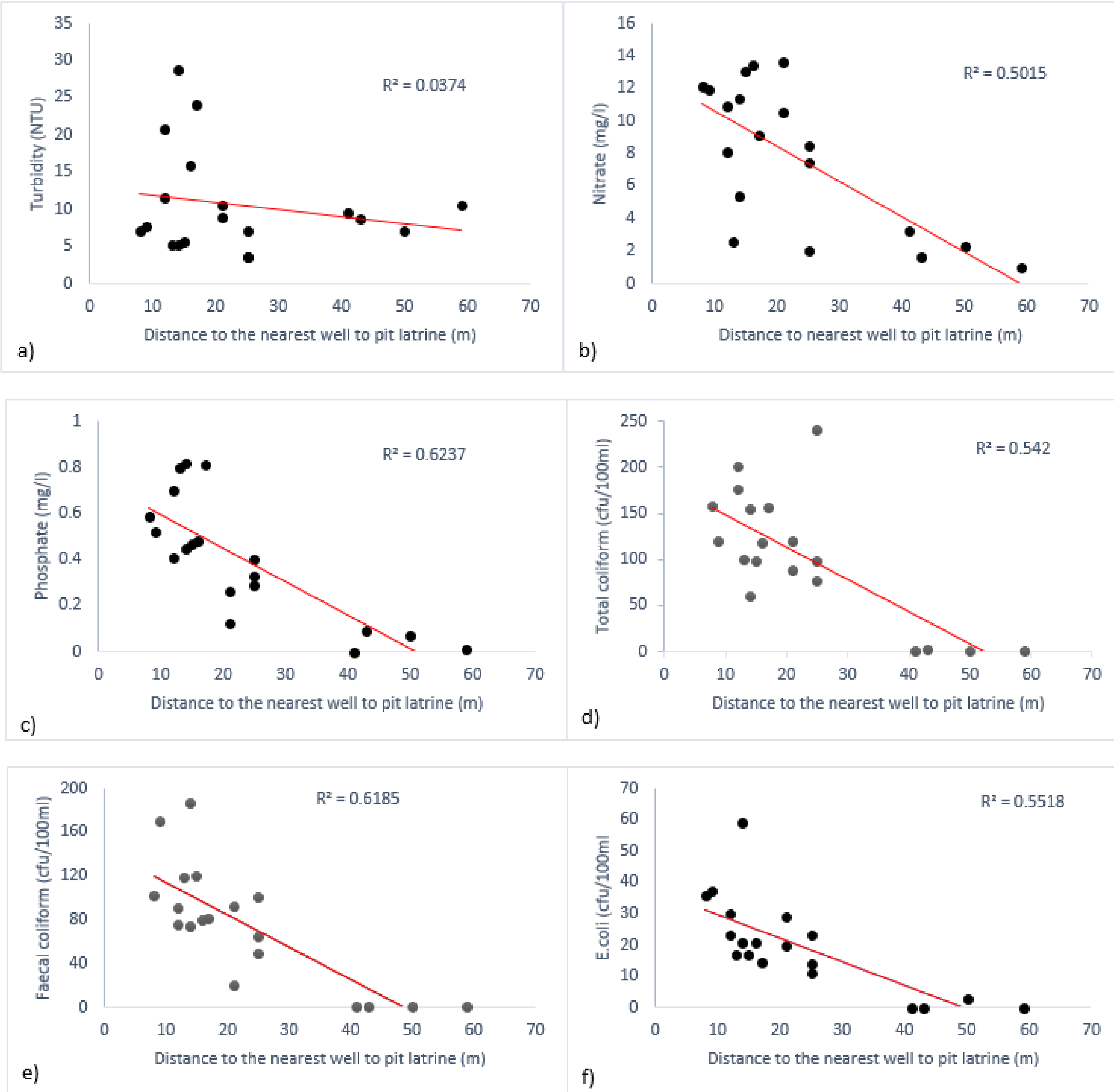

Figure 4. Distance to the nearest pit latrine versus observed wells a) Turbidity, b) Nitrate concentration, c) Phosphate concentration, d) Total coliform, e) Fecal coliform, f) *E. Coli*.

Nitrate concentration ranges between 1.00 and 13.59 mg/l, with an average standing of 7.79 ± 4.49 mg/l. The values in **Table 3** show that the nitrate concentration above in 8 of the 19 sampling wells in higher than the WHO standard of 10 mg/l. This means that less than two-fifth of the sampled wells are polluted with nitrate. The equation of the regression line (**Figure 4b**) between the nearest pit latrines and the nitrate concentration of the sampled wells is y = -0.2175x + 12.83. The target concentration is 10mg/l; for y = 10 mg/l, we get x = 13.02, and the minimum distance between pit latrines and wells is D_2 = 13.02 m; R^2 = 0.5015 which means that only 50.15% of the nitrate value depends on the change of wells spacing. It is highly significant, so we can assume that the concentration of nitrate in groundwater depends on distance.

Phosphate concentration ranges between 0.00 and 0.82 mg/l with an average of 0.40 ± 0.27 mg/l (**Table 3**). Phosphate levels in all domestic wells are lower than those recommended by WHO, which means that water is free of phosphate pollution. The equation of the regression line (**Figure 4c**) between the nearest pit latrines and the phosphate concentration of the sampled domestic wells is y = -0.0145x + 0.7363. The target concentration is 0 mg/l; we get x = 50.78, and the minimum distance between pit latrines and wells is D_3 = 50.78 m; R^2 = 0.6237 which means that only 62.37% of the phosphate value depends on the change of well spacing. The difference of pollution levels is caused by the different characteristics of wells in the study area. These characteristics include type of coverage, number of residents and distance from the nearest pit latrines.

Table 3. Water quality results. In situ parameters for 19 water samples.

Item	Turbidity (NTU)	Nitrate (mg/l)	Phosphate (mg/l)	Total coliform (cfu/100ml)	Fecal coliform (cfu/100ml)	*E. coli* (cfu/100ml)
Min	3.52	1	0	0	0	0
Max	28.83	13.59	0.82	240	186	59
Average	10.59	7.79	0.40	103.25	74.71	19.79
SD	7.00	4.49	0.27	69.85	54.50	14.79

Some well water samples were observed to be contaminated by total coliform (TC), fecal coliforms (FC) and *E-coli*. 84% of the wells contain a large amount of *E-coli*., and 79% of the wells contain a large amount of total coliforms and fecal coliforms respectively. The average microbial counts of *Escherichia coli*, TC and FC were 19.79 ± 14.79 cfu/100mL, 74.71 ± 54.50 cfu/100ml and 103.25 ± 69.85 cfu/100mL, respectively (**Table 3**). The average distance between the water samples from the wells and the pit latrines is 23.11 ± 14.62 meters. The total number of coliforms in almost all sampled wells is higher than that of fecal coliforms and coliforms. **Figure 4 (d, e, f)** gives distance to the nearest pit latrines versus observed wells concentrations for TC, FC and *E-coli*. The equation of the regression line is y = -3.5192 x + 184.76 for TC, y = -2.9338 x + 142.73 for FC and y = -0.7518 x + 37.206. The minimum distance between pit latrines and wells water samples of TC, FC and *E-coli* is D_4 = 52.50 m, D_5 = 48.65 m and D_6 = 49.49 m respectively. TC (R^2 = 0.542), FC (R^2 = 0.6185) and *E-coli* (R^2 = 0.5518) are highly significant, so it can be assumed that the concentration of total coliforms, fecal coliforms and *E-coli* in groundwater depends on the distance from the pit latrines. There was a moderate negative Pearson correlation (r = -0.737, r = -0.786 and r = -0.744) with a significant p value ($p < 0.01$) between pit latrines distances and TC, FC and *E-coli* (**Table 4**). In this study, there was a significant positive correlation and P value between TC and FC (r = 0.534, p = 0.02), TC and *E-coli* (r = 0.571, p = 0.01), FC and *E-coli* (r = 0.860, p <0.01) was observed (**Table 4**).

Table 4. Results of multiple regression analysis.

Parameter	Pearson correlation r	p Value
Distance between pit latrines and wells TC concentration	-0.737	< 0.01
Distance between pit latrines and wells FC concentration	-0.786	< 0.01
Distance between pit latrines and wells *E. Coli* concentration	-0.744	< 0.01
Relation between TC and FC wells concentration	0.534	0.02
Relation between TC and *E. Coli* wells concentration	0.571	0.01
Relation between FC and *E. Coli* wells concentration	0.860	< 0.01

The minimal average distance required between pit latrines and all parameters of domestic wells water samples is Dmin = mean (D_2; D_3; D_4; D_5; D_6) = 42.89 m. D_1 is not used since the degree of significance of the simple linear regression is too low.

The minimal distance needed between pit latrines and wells is 42,89 ± 16.76 m. Now that we have computed the minimal distance needed between domestic wells and pit latrines, let us check the situation on site.

Fifty-six non-sampled wells were recorded in the study area. Only seven of them are built at least 42.89 m away from the pit latrines. That makes only 12.50 % of domestic wells that can be supposed uninfected with regard to on-site sanitation. This makes only 12.50% of household wells considered uninfected in terms of on-site sanitation. As a result, 87.50%

of household wells in the region were infected. **Figure 5** shows a map showing the impact range of all pit latrines and household wells identified in the area. Abundant pit latrines mean that a large number of wells are located near the sources of fecal pollution. In fact, the spatial database shows that about 89% of the wells are within 27 meters of a pit latrines, 8% between 27 and 43 meters and only 3% outside the pit impact area **Table 5**.

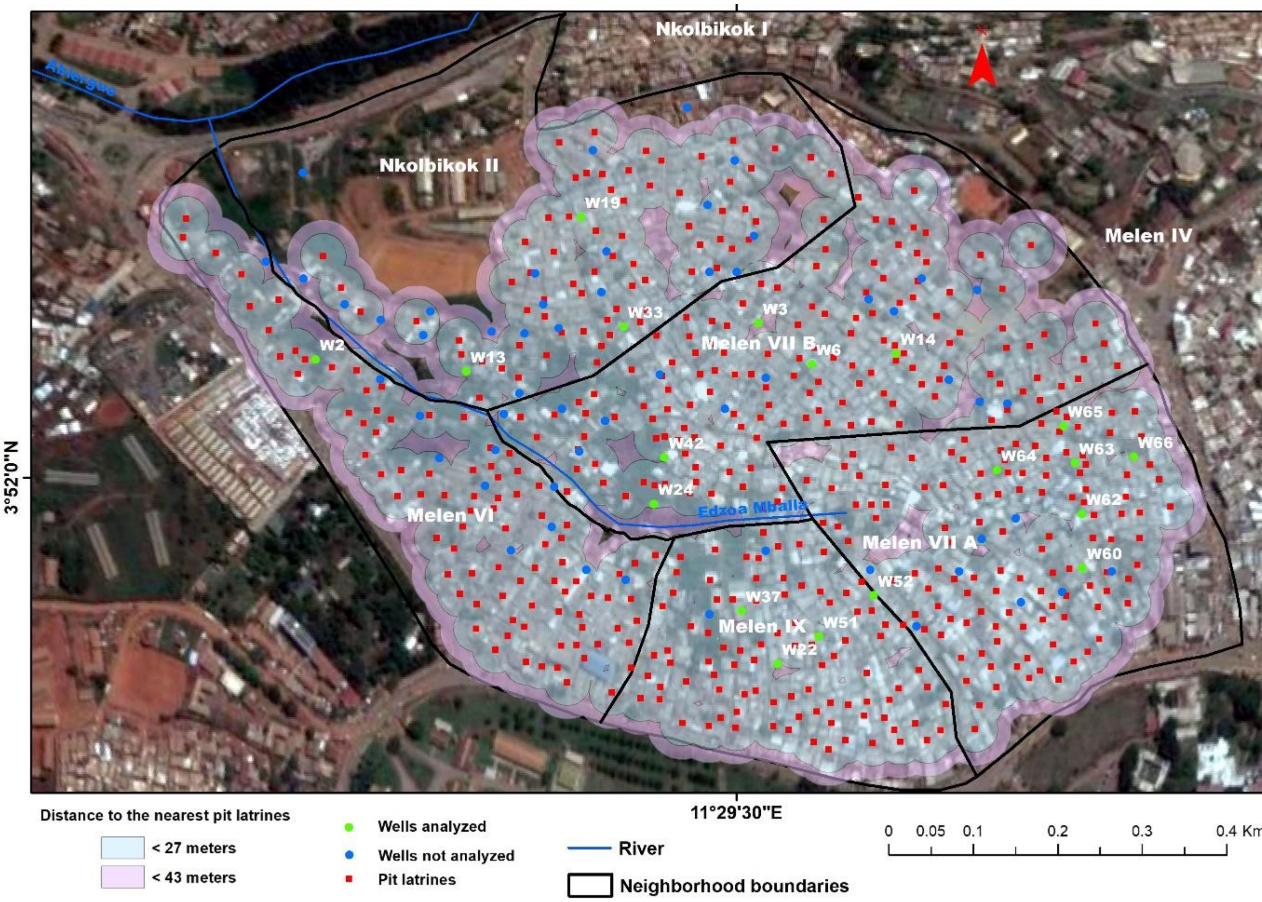

Figure 5. Buffer zone of pit latrines, considering 27 and 43-meters radius influence.

Table 5. Well location in relation to buffer zone pit latrines in the study area.

Quarters	Total wells	Wells within 27 m of a latrine (%)	Wells within 27 to 43 m of a latrine (%)	Wells located more than 43 m away (%)
Melen VI	12	92	8	0
Melen VII A	14	100	0	0
Melen VII B	19	89	11	0
Melen IX	6	83	17	0
Nkolbikok II	24	84	8	8
Total	75	89	8	3

The map show in **Figure 6** is produced to estimate the density of pit latrines in groundwater in the study area. Red indicates that the concentration of pollutants in groundwater is very high, which is caused by a large number of pit latrines within 42.89 m. Yellow indicates that the pollution is not serious, and green indicates areas far enough from on-site sanitation for the groundwater to be infected. From the map, we can notice that the groundwater in the area is polluted.

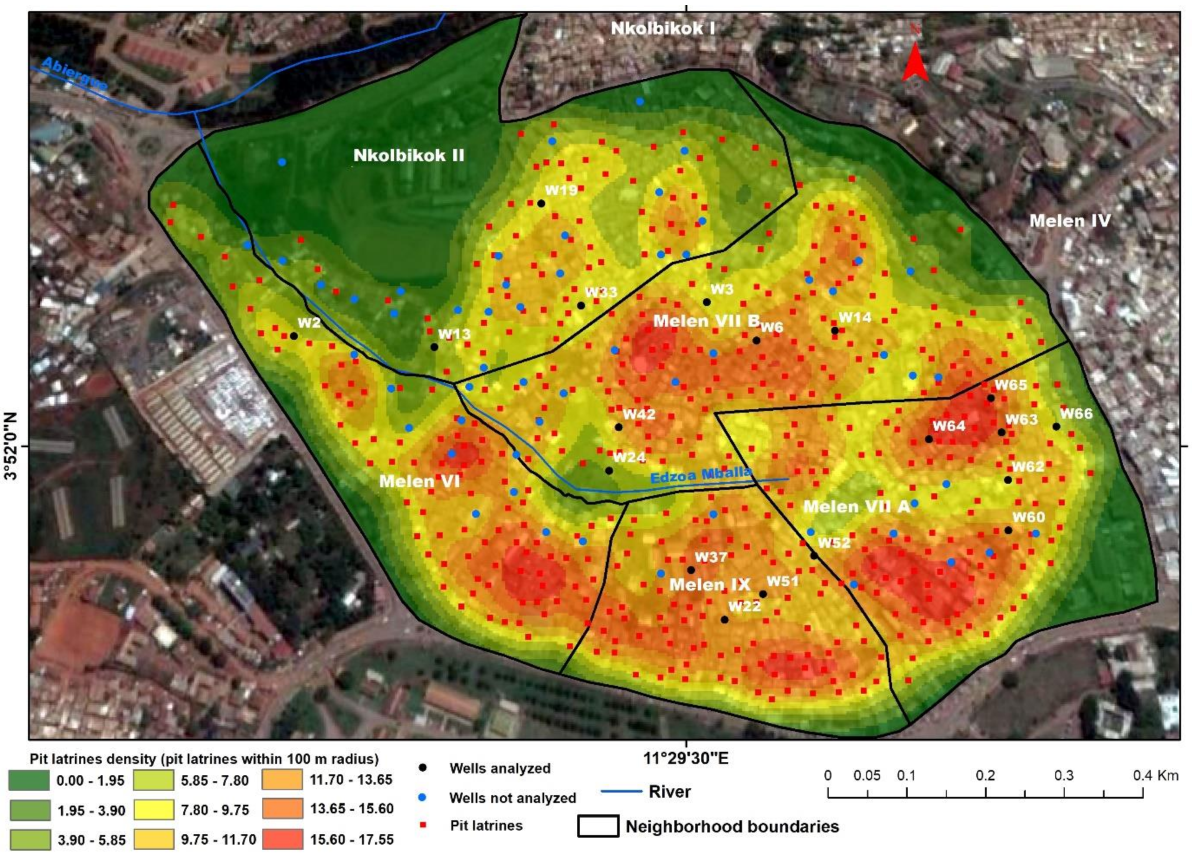

Figure 6. Pit latrines density map.

DISCUSSION

The source of bacteria in groundwater is still little known [26,27] believe that most bacteria in groundwater originate from the surface environment through the transport of pollutants during infiltration from surface water to groundwater. Therefore, bacteria in groundwater are not equally important to the quality of drinking water. Therefore, the analysis of groundwater biological parameters includes the search for bacteria. Their sources are diverse, but in developing countries, the presence of bacteria in groundwater is attributed to the lack of sanitation of domestic wastewater and especially in pit latrines [28].

The results of this study show that the pollution of groundwater by pit latrines is still a major problem in developing countries, especially Melen.

The results presented in this study suggest that the bacteria (TC, FC and *E-Coli*) present in most of the sampled wells are out of range. The pollution comes from the pit latrines close to the well. A previous study in Mali confirms that when the well is close to the latrine, the bacterial content is high [29].

Some protected wells were also found to have high levels of bacterial contamination (w64 and W6), which may be due to pit latrines near the well. Since this study was conducted in the dry season, due to insufficient rainfall throughout the year, it is impossible to conduct a comparative study between the rainy season and the dry season. However, a study in Bhopal, India [30] showed that the higher concentration of coliform in the dry season is due to the faster bacterial transport during this groundwater recharge period.

An attempt was made to correlate the distance between the nearest wells with chemical and bacteriological parameters, and it was found that the correlation values of several parameters other than turbidity were almost satisfactory. In this study, the minimum distance between the wells and the latrines is 42.89 ± 16.76 m. This result on the minimum distance between the wells and the latrines is equivalent to 15 m quoted by the World Health Organization [19]. Parker [31] summarized the minimum distances in national guidelines, such as 25 meters in Burkina Faso, 30 meters in Ethiopia, 50 meters in Ghana, 15 meters in Mali, 50 meters in Uganda and 30 meters in Mozambique.

The latrine density map shows a strong correlation between latrine density and non-sampled wells, indicating that these wells may be contaminated, and some users of non-sampled wells claim that they sometimes suffer from water-borne diseases. Martınez-Santos [29] observed a similar situation in Diawarrala, Fyenkala and Dougouyala villages in Western Mali.

Since most drinking water wells are polluted due to their proximity to pit latrines, one way to improve the quality of drinking water supply is to establish a decentralized treatment system in the family, install underground tanks near the wells and disinfect them with bleach every week.

CONCLUSION

Pit latrines may be an important source of well water pollution if not all precautions are taken. The depth of pit, soil permeability and the design of pit latrines can play a key role in groundwater pollution risk assessment. The purpose of this study was to estimate the minimum distance required for groundwater remediation through these remediation measures, and establish the relationship between the collected data and the analysis parameters of pit toilets and wells. This distance is 42.89 meters, and more than 97% of wells do not comply. For example, 97% of wells provide contaminated water to households. More than 59.3% of the study area was polluted. In order to avoid greater pollution of groundwater, the sanitary conditions of all buildings under construction or existing buildings must be improved. Since the collective system is unimaginable without destroying most buildings and rebuilding the area according to urban planning, the only remaining solution seems to be a centralized or semi centralized wastewater system. These systems are very similar to the field system, but have the particularity of treating a certain amount of construction wastewater in the same area.

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DECLARATION

Conflict of interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are available from the corresponding author upon request.

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AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Boris Merlain Djousse Kanouo, William Teikeu Assatse, Kasi Njeudjang; Zakari Aretouyap, Georges Nshagali Biringamine and Philippe Njandjock Nouck. The first draft of the manuscript was written by Boris Merlain Djousse Kanouo and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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