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Contamination of groundwater sources in emerging African towns: the case of Babati town, Tanzania

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Abstract

Assessment of groundwater contamination potential was carried out in Babati, Manyara, Tanzania. Diazotization, cadmium reduction, ascorbic acid, ion selective electrode and membrane filtration analytical methods were used, respectively, for nitrite, nitrate, phosphate, fluoride and microbial investigations. Fecal coliforms (FC) and high NO_3 concentrations were present in wells less than 30 m deep. The maximum FC level was 280 CFU/100 ml, and the nitrate (NO_3) ranged from 1.1 to 357.7 mg-NO_3/l. In boreholes, nitrate concentrations ranged from 2.3 to 32.6 mg-NO_3/l, below both national and WHO standards, and were all free of fecal coliform. Other parameters were all within recommended limits for all wells tested. Evaluation of the potential contamination pathways revealed that the shallow well depths ranged from 1.2 to 26.67 m – median 9 m ($N = 366$): 70% were unlined and 19% were uncovered. About 74% of the wells were within 30 m of sanitation facilities, of which 60% were traditional pit latrines. The findings revealed that most shallow wells (64%) are polluted and could cause health problems for users. Therefore, it is prudent that the community avoids relying on shallow wells. Boiling of domestic water before use is highly recommended.

Key words: emerging towns, groundwater sources, pollution risk, water pollution

INTRODUCTION

Groundwater is a vital source of drinking water and the main source of water supply in both rural and urban populations (Palamuleni 2002). Groundwater is thought to provide potable water to about two billion people, as well as 42% of irrigation water, contributing to about 40% of world food production (Morris *et al.* 2003). In countries like India, for example, 85 to 90% of rural dwellers depend on groundwater for drinking and more than 250 km^3 is used in agriculture annually (Shah & Kulkarni 2015). In sub-Saharan Africa (SSA) groundwater has become a preferred water source in many cities to meet demand from growing populations. In a city like Lusaka, 55% of the water distributed by public utilities comes from boreholes (Foster 2017). It is also estimated that about 100 million people in small towns and villages in SSA depend on groundwater and other sources for drinking and other domestic purposes (Pavelic *et al.* 2012), with poor town-dwellers relying on their own wells. Such sources are prone to pollution from sources including pits latrines, storm water and other unsanitary forms of waste management (Tillett 2013).

Several studies evaluating the effects of sanitation facilities on water sources have revealed cases in which pit latrines were the main cause of groundwater contamination (Wright *et al.* 2013; Sorensen *et al.* 2016). For instance, Wright *et al.*'s study (2013) in the peri-urban area of Kisumu, reported positive thermo-tolerant coliform counts and NO_3 values above the WHO limit of 10 mg-N/l, in

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groundwater samples obtained near pit latrines. The construction of latrines near water sources increases the risk of water pollution.

A similar study in Kampala also revealed significant nutrient pollution in groundwater from shallow aquifers underlying pit latrines (Nyenje *et al.* 2013). Other investigations that have reported contamination include that of Sorensen *et al.* (2014) on 'emerging contaminants', in which up to 1.8 mg/l of insect repellent (diethyltoluamide) was detected in groundwater from shallow wells in low-cost housing areas, and associated with poor sanitation infrastructure, inadequate waste disposal and poor well protection – the study was done in Zambia.

In Tanzania, the supply of safe drinking water has remained a challenge, with poor communities relying on shallow wells, springs, rivers, streams and ponds for their daily domestic water needs (Pauschert *et al.* 2012). Babati is among the faster growing towns in Tanzania, and the population growth and distribution, and increasing development have led to increased water demand. Many residents now depend on groundwater sources, mostly from shallow onsite wells for drinking and other domestic use. The easy access to groundwater because of the shallow water table, and the cost of piped water connections and monthly water charges from the official water utility, have led many households to rely on private wells rather than Babati Urban Water Supply and Sanitation (BAWASA). It is well established that consumption of water from impromptu sources (mainly shallow wells) with unknown quality results in significant numbers of people suffering from waterborne diseases (Elisante & Muzuka 2016). The shallow wells are constructed on small plots with no account taken of potential adverse impacts arising from nearby sanitation facilities, well protection or other pollution sources. Most sanitation facilities in the area are reported to be poorly constructed, and hence likely to contaminate the environment and increase the risk of water contamination (URT SNV 2014). In Tanzania 23,900 children under five years old are reported as dying each year from dysentery and diarrhea linked to the consumption of unsafe water (Elisante & Muzuka 2016).

The aim of this study was to assess the potential for groundwater contamination in the urban setting of a small town. It was also intended to provide information concerning the proximity of wells to sanitation facilities, the management status of water sources, and the dominant water collection methods and their potential influence.

MATERIALS AND METHODS

Study area

The study was conducted in Babati, Manyara, Tanzania, latitude 4° 12′ 28.18″ S, longitude 35° 44′ 46.13″ E, and elevation 1,392 m above sea level. In the 2012 census the town's population was 93,108 and it covered just over 460 km^2 (URT 2013a). Rainfall in Babati is largely unimodal, characterized by a rainy season lasting roughly from October to May and a dry season between June and September (Ströomquist & Johansson 1990).

Data collection

Groundwater sources and sanitation facility information

Groundwater sources and sanitation facilities were surveyed in all Babati's wards (Figure 1), to evaluate their condition and relative proximity. A Global Positioning System (GPS) device was used to record the locations, and information on well depth, sanitation/latrine type and depth, disposal options and emptying frequencies obtained with a questionnaire. A checklist was used for sanitary risk inspections of the wells – see Table 1. Groundwater levels were measured in wells using a Geotech meter capable of operating to depths of 100 m.

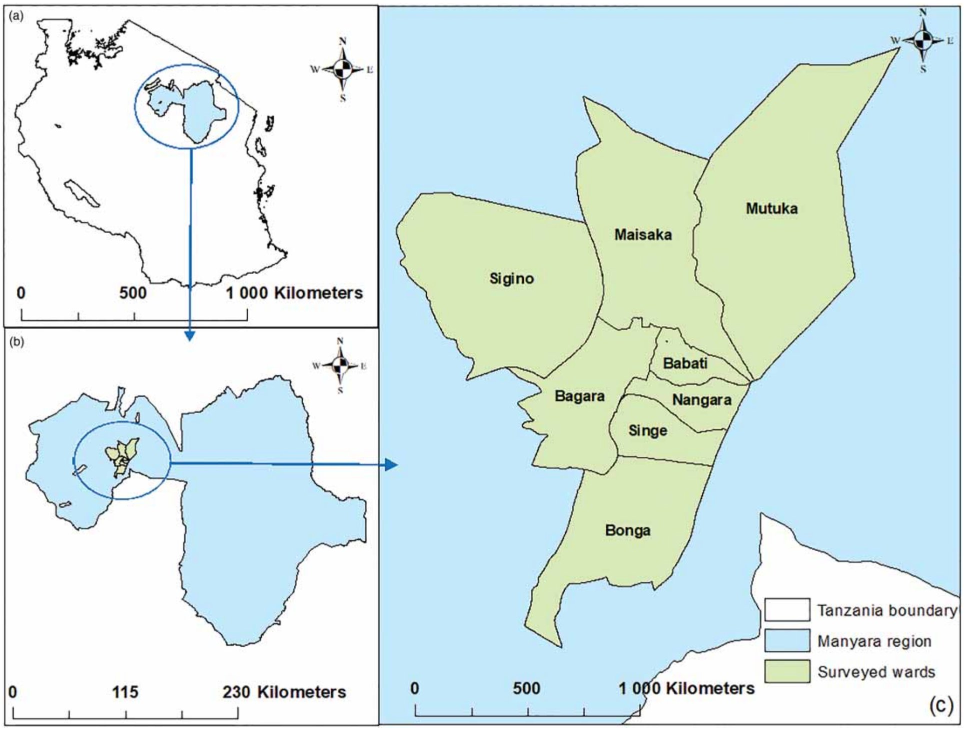

Figure 1 | Babati and the town wards.

Table 1 | Questions for sanitary risk inspection for groundwater sources

A	Is there a pit latrine near the well within 10 m?	Y/N
B	Is there any dumping yard for animal and or domestic wastes within 10 m of the well?	Y/N
C	Is there any pond of standing water around the concrete floor of the well?	Y/N
D	Is there surface water found within 10 m to the well?	Y/N
E	Is there a pit latrine on higher ground than the well?	Y/N
F	Are there cracks on cement floor surrounding the well?	Y/N
G	Is the cover of the well in adequate cleanness?	Y/N
H	Are there other latrines within 30 m of the well?	Y/N
I	Are there any uncovered wells within 30 m of the wells/borehole?	Y/N
J	Is the concrete floor less that 1 m around the well?	Y/N
K	Is there inadequate fencing around which might permit animals in?	Y/N

Water sampling and laboratory analysis

Sampling design

The source classifications were determined and well groups for sampling formulated on the basis of well depths and the methods used to draw water. Both shallow wells with manual water extraction by buckets (<30 m) and pumped boreholes were sampled (Tables 2 and 3). However, during the study none of the water sources was being operated by manual extraction.

Onsite tests and water sampling

Water sampling was carried out in June 2017 from 50 groundwater sources, using a stainless steel container on the end of a rope. A portion of each sample was tested on-site for electrical conductivity (EC),

Table 2 | Concentrations of physicochemical parameters in groundwater determined onsite

	Shallow wells				Boreholes	
	Water extraction method				Water extraction method	
	Pump		Bucket		Pump	
Parameter	Min	Max	Min	Max	Min	Max
EC (μS/cm)	349	1,554	535	3,252	664	1,315
TDS (mg/l)	239	1,010	347	2,116	430	853
Temp (°C)	22.5	31.7	21.6	26.15	23	27.4
pH	6.62	7.68	6.67	7.52	7.22	7.69
Sal (PSU)	0.13	0.77	0.22	1.68	0.27	0.57
Turb (FTU)	0	7.87	0	16.42	0	0

Table 3 | Physical, chemical and microbial concentration ranges in groundwater, against water collection methods

	Shallow wells				Boreholes	
	Water extraction method				Water extraction method	
	Pump		Bucket		Pump	
Parameter	Min	Max	Min	Max	Min	Max
NO_3 (mg/l)	4.4	229.8	1.1	357.7	2.3	32.6
NO_2 (mg/l)	0.002	0.65	0.01	1.18	0.01	0.27
PO_4^3 (mg/l)	0.04	0.99	0.03	1.03	0.08	0.57
TP (mg/l)	0.01	0.3	0.01	0.34	0.03	0.18
COD (mg/l)	<LoD	25	<LoD	76	6	30
F^- (mg/l)	0.42	2.07	0.18	2.16	0.66	2.27
FC (CFU/100 ml)	0	224	0	280	0	0
TC (CFU/100 ml)	0	420	2	610	0	56

total dissolved solids (TDS), and dissolved oxygen (DO), pH, and temperature, using a Palintest® Macro 900 meter. Turbidity was tested using a HANNA multi-parameter instrument (model HI93703). The rest of the sample, intended for tests for nitrate, total phosphorus, phosphate, COD and fluoride, was transferred to a sterile plastic container and sealed. The sealed containers were labeled and placed in a cool box at <4 °C, and transported to WESE laboratory of the Nelson Mandela African Institution of Science and Technology for analysis. To avoid cross-contamination, during sampling the new rope was used for each water source i.e. after a single use the rope was discarded. Ethanol (70% v/v) was used to sterilize the containers before rinsing with distilled water, and concentrated sulfuric acid was added until pH 2.0 was attained.

Membrane filtration (MF) was used to test for fecal coliform bacteria and total coliforms (TC), using a Palintest kit (Wagtech 2) for site sterilization, filtration and incubation. 50 ml of each sample was filtered through 0.45 micron membrane filters using a sterilized vacuum filter. Sterilized forceps were used to remove the filters from the vacuum holder and place them in pre-labeled petri dishes containing membrane lauryl sulfate broth base. The dishes were incubated for 18 hours in Wagtech incubators at 44.5 and 37.0 °C for fecal and total coliform bacteria, respectively. Viable colonies were counted using a lens.

Sample preparation and analysis

Fluoride (F), nitrate, nitrite, COD (medium range, 0 to 15 mg/l) and phosphate were determined in the laboratory. The cadmium reduction method 4500-NO_3 and NitraVer5 nitrate reagent powder was used to determine nitrate, with NitraVer3 nitrite reagent powder to test for nitrite by the diazotization 4500-NO_2 standard method. Ascorbic acid was used to determine phosphate using PhosVer3 reagent vials, and PhosVer3 with acid persulfate digestion to determine total phosphorus. The reagents used and methods are USEPA accepted for water analysis using Hach methods**.** COD and fluoride were determined by reactor digestion (USEPA standard 5220D) and ion selective electrode (method EPA 45-F-C) methods as per manufacturers respectively (Hach Company 2002). A Hach instrument (DR2800) was used to determine nitrate, nitrite and phosphate concentrations.

Data analysis

Descriptive statistics was used to correlate the determined values against well distances from sanitation. The groundwater quality parameters represented are the actual values determined in the laboratory, and are expressed as a range of minima and maxima.

RESULTS AND DISCUSSION

Groundwater source distribution

The groundwater source distribution is shown in Figure 2. In total 435 identified sources were identified in the vicinity of Babati, of which shallow wells – depth less than 30 m – represented 366 (84%) and deep wells (>30 m) about 20 (5%). The depths of 49 wells (11%) could not be tested and no depth information was available for them. The depths of the shallow wells ranged from 1.2 to 26.67 m – median 9 m ($N = 366$). All of the boreholes, which were mostly operated by BAWASA, were more than 70 m deep.

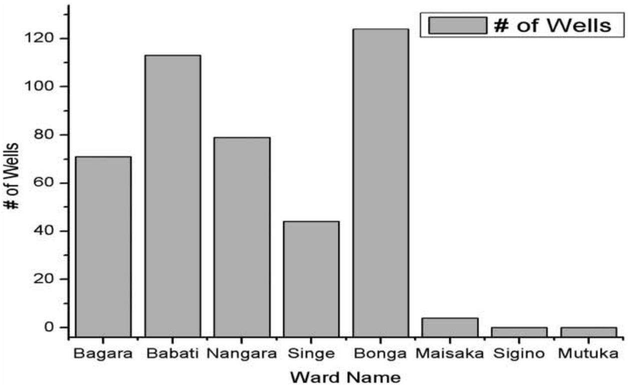

Figure 2 | Groundwater source distribution by ward.

About 208 (48%) of the groundwater sources were within 15 m of toilets, of which 60% were traditional pit latrines. Some 82 (19%) of the sources were uncovered, and 70% were unlined and/or had no shoulders.

Of all the sources identified, 389 (89%) were privately owned, at homes or places like hotels, and the rest were community wells, some of which were operated by BAWASA or village/street communities. Various abstraction methods were used including electric or hand pumps, and manually operated rope and bucket systems, the latter comprising 277 (62%) of sources. BAWASA boreholes were dominant in Babati, Bagara, and Nangara wards, and some parts of Singe and Maisaka wards (Figure 3).

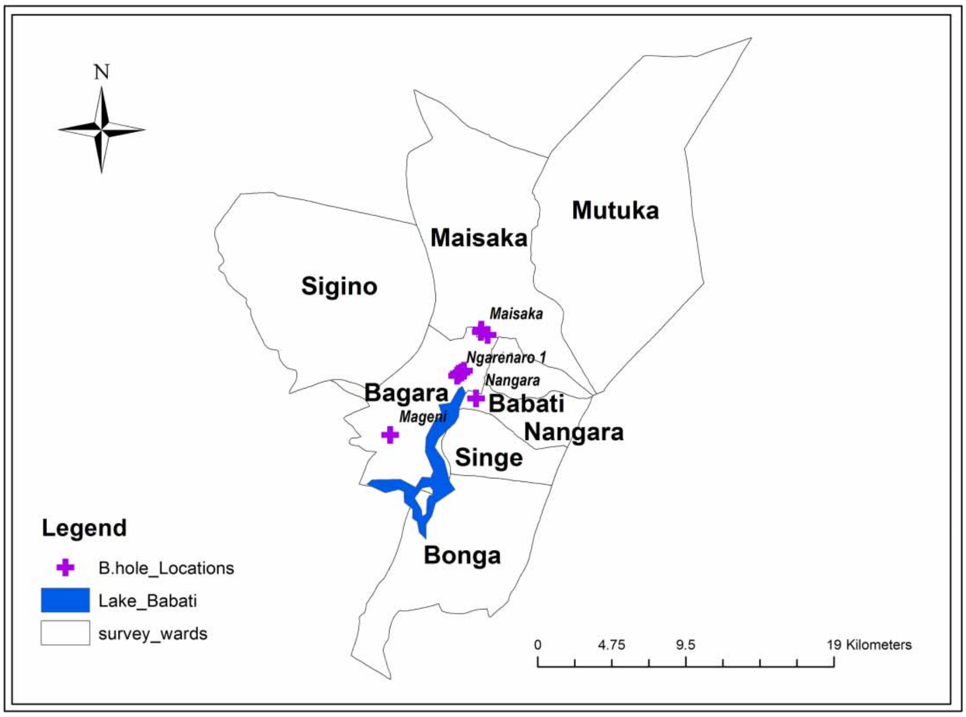

Figure 3 | BAWASA operated boreholes.

Sanitation facilities – types and distribution near groundwater sources

The numbers of sanitation facilities found within 60 m of wells, and their types and distribution by ward, are shown in Figure 4. Babati ward had the highest number of toilets close to water sources, perhaps because it is at the town center, where the population density is relatively high.

The mean depth of the toilets evaluated is 3.47 ± 0.05 m ($N = 621$, $P < 0.05$), of which there were 373 traditional pit latrines (60%). Pit latrines were generally more common on the town's outskirts, which is linked to the economic status of the resident communities (Magner 2008). The town center, on the other hand – parts of Bagara and Babati wards – housed greater numbers of better quality toilets (flush and pour-flush into septic tanks). The higher proportion of better quality toilets was linked to various investments and good standard residential houses with access to existing infrastructure, including connections to main water supply and electricity, and transport and other services.

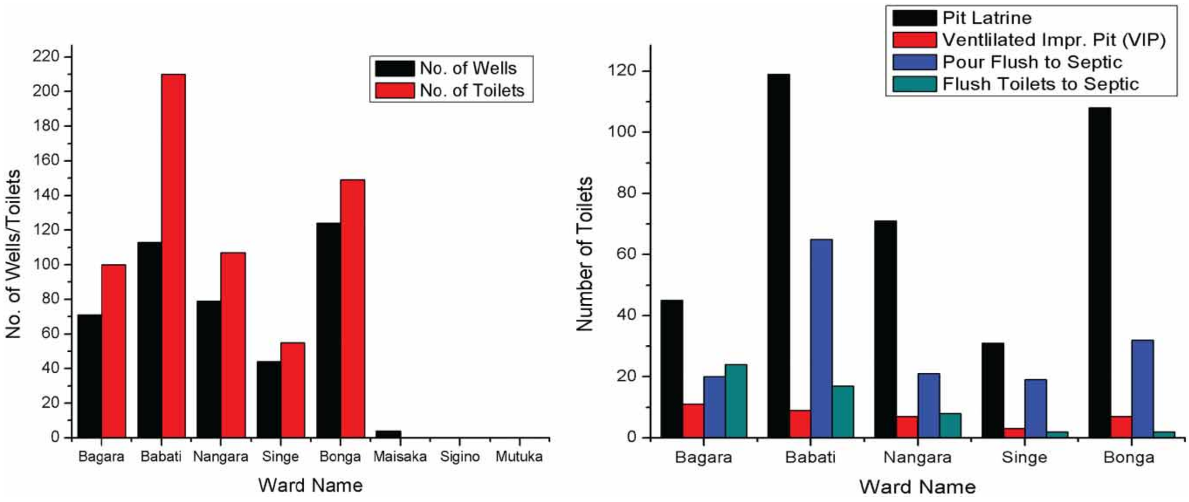

Figure 4 | Numbers of wells and sanitation facilities within 60 m of each other, by ward.

Poorly developed sanitation infrastructure is reported in emerging towns like Babati in developing countries. Ineffective enforcement of existing laws, and lack of close follow-up of implementation directives by local government authorities and the responsible utility companies, are reported to contribute to the problem in towns (Seetharam 2015). Effluent release to the environment from poorly designed toilets increases the risk of groundwater contamination as it can find its way through the soil to the water table. Therefore the observed proximity of water sources to these types of toilet needs to be addressed to protect groundwater from pollution. To control contamination from these sources, United Republic of Tanzania (URT) has established national guidelines for the management of liquid wastes in which it is recommended that pit latrines are sited as far as possible from water sources, with a minimum separation of 30 to 60 m and an absolute minimum of 15 m (URT 2013b). This needs to be enforced to preserve the town's groundwater resources.

Groundwater quality analysis and risks of contamination

Onsite parameter – test results

EC, TDS, pH, salinity, temperature and turbidity

The concentrations for parameters tested in-situ are presented in Table 2. The statistical correlation results for EC, TDS, pH, temperature and salinity against well types relative to water collection methods showed a varying concentration values, with the exception of turbidity. The EC varied from 664 to 1,315 μS/cm in boreholes and from 349 to 1,554 μS/cm (median 801 μS/cm) for pumped shallow wells, and 535 to 3,252 μS/cm (median 727 μS/cm) in sources where buckets were used. TDS minimum and maximum concentrations were 239 and 2,116 mg/l, and were obtained in shallow well water. The concentration/value distributions for EC, TDS, temperature, salinity, pH and turbidity were non-uniform among well types versus water collection methods. However the mean test parameter concentrations were higher in the boreholes than the wells, apart from low turbidity in the borehole waters. Concentration variations appeared to be associated with the source location and the nature of the metamorphic bedrock there. According to WHO, water is considered potable when the TDS concentration is below 600 mg/l and non-potable when it exceeds 1,000 mg/l. The turbidity in all boreholes was 0 FTU, while for shallow wells it ranged from 0 to 16.42 FTU and 0 to 7.87 FTU, respectively, depending on whether the water was drawn by bucket or pump. The WHO recommended limit is 5.0 FTU. The variation in turbidity was attributed to the means of water collection and inadequate well head cover hygiene – possible dust sources because of water returning to the well during withdrawal by buckets and/or when opening well covers.

Laboratory analytical results

The concentration values for the chemical species determined are presented in Table 3. The nitrate (NO_3) results showed significant variation in concentration between the groundwater sources sampled, with the higher values in shallow wells (Figure 5). The highest value determined was 357.7 mg-NO_3/l, which exceeds the national and WHO recommended levels – 70 and 50.0 mg-NO_3/l for drinking water respectively (2008), and was reported from shallow wells. The concentration ranges (mg-NO_3/l) for shallow wells were: bucket-operated – 1.1 to 357.7 with a median of 18.5; and, pump-operated – 4.4 to 229.8 with a median of 24.7. The nitrate concentrations in boreholes ranged from 2.3 to 32.6 mg-NO_3/l with a median of 5.45. These results indicated that water collection methods have a low to negligible influence on nitrate concentration. The highest concentrations were determined in wells in Mji mpya and Babati wards, which are near the bus terminal in the town center, where the concentration of buildings is relatively high. The density of settlement in the area is associated

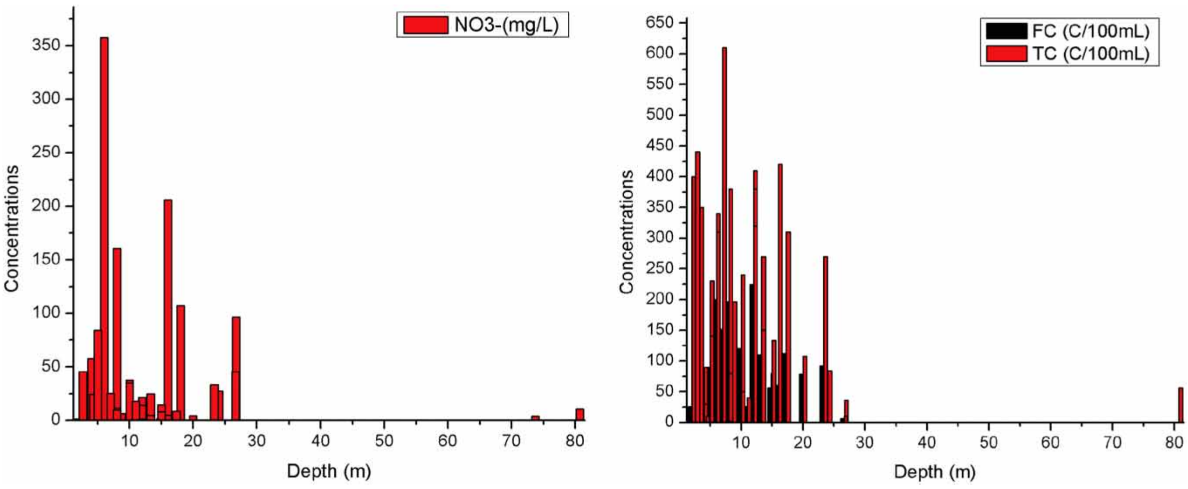

Figure 5 | Correlation of NO_3 and microbial concentrations with well depth.

with the existence and accessibility of transport services. Latrine densities at such locations with wells close to them and within 60 m were greater than any other surveyed wards. The standard deviations in nitrate concentration for shallow wells were 74.8 (bucket) and 70.0 (pump), and for borehole waters 11.6. The variation in nitrate levels may be attributable to various sources including seepage from nearby septic tanks and/or contaminated wells, and other waste water and refuse released to the environment from domestic works and during fertilizer application. High nitrate levels are highlighted by Elisante & Muzuka (2015) as occurring in other parts of Tanzania.

For nitrite (NO_2), the maximum concentration determined was 1.18 mg-NO_2/l, which is below the WHO recommended maximum of 3.0 for drinking water. (At present Tanzania has no nationally prescribed maximum nitrite concentration.)

Microbes: The microbiological contamination results revealed a remarkable number of sources polluted with both fecal and total coliforms. They also showed that the highest concentrations were in the shallow wells, regardless of the water collection method employed. The mean concentrations reported varied between well types versus water collection methods, a result that be caused by the different finishing/design of individual wells, their locations and the methods used to draw water. The use of bucket and rope to collect water is considered unsafe because water falling back during collection may increase contamination levels. The high number of wells was found unlined 305 (70%), these are also a potential pathway for microbial contamination (unlined and improperly sealed wells walls increases the risk of contamination from the leaking vertical portion of the well). Other potential causes of the extent of contamination variation include the sanitation facilities found near water sources and polluting activities taking place close to wells.

In boreholes, the maximum TC and FC concentrations were 56 and 0 CFU/100 ml respectively. Only one of the six boreholes tested reported the presence of TC, all other borehole-TC values being below the limit of detection (Figure 5). These results indicated that the microbial contamination values exceeded WHO standards (0 CFU/100 mL) for FC in the shallow wells, the boreholes appeared to be safe. The standard deviations in microbial concentrations determined for the shallow wells (all CFU/100 ml) were: bucket-operated TC 150, FC 75; pump-operated TC 146, FC 72; and, boreholes TC 23, FC 0.

Coliform bacteria are present in the environment and feces of humans and all warm blooded animals. Their presence, because of source contamination and/or water treatment failure, is associated with waterborne diseases including nausea, vomiting, fever and diarrhea (Smith 2001).

TP and PO_4: The maximum concentration of TP was 0.34 mg/l and distribution was non-uniform among the wells. The standard deviation was roughly 0.1 mg-TP/l. Variations in phosphorus content between hydrologic sites can be attributed to both the natural mineral composition in the area and the application of phosphorus fertilizers on farms (Ulén & Snäll 2007). Phosphorus fertilizer is absorbed inefficiently and, during rainfall, can be transported by flowing water, causing varying concentrations in nearby water bodies. Phosphorus is essential for both plants and animals, and occurs naturally in rocks. During weathering it is released as phosphate ions, which are soluble in water. The PO_4^{3-} concentrations determined were between 0.03 and 1.03 mg/l, below the WHO recommended maximum of 6.0 mg/l. Consumption of water containing high phosphate concentrations is associated with digestive health problems (Domagalski & Johnson 2012).

COD: The maximum concentration recorded was 30 mg/l and statistical analysis of the results indicated a significant variation, implying varying groundwater solute content around Babati, depending on location. However, the mean values exceeded the WHO recommended maximum of 10 mg/L in borehole waters, whereas the shallow wells conformed. COD concentrations indicate the amount of oxidizable matter dissolved in water that can take up DO, which can occur to such an extent to be detrimental to aquatic life.

F: fluoride concentrations were in the range of 1.18 to 2.27 mg/l – i.e., entirely within the recommended maximum of 4.0 mg/l. The statistical analysis showed significant variation ($P<0.05$), thought to be associated with the mineral composition of the local bedrock. Consumption of high amounts of fluoride can cause fluorosis in children's teeth, which has been reported occasionally as causing death (Rao *et al.* 2015).

Sanitary risk inspections: The sanitary risk inspection score is shown in Figure 6. The assessment was based on the yes/no ratio of the variable (Table 1), whereby higher positive responses indicate a greater risk of contamination. The results showed that sanitation within 30 m of wells was the most common problem, and that a remarkable number of wells 102 (23%) were actually within 10 m of sanitation. It was also clear that there was a higher risk of contamination in wells closer to sanitation (Figure 7) as the nitrate and fecal coliform data show decreasing concentration levels with increasing distance to latrines. Other issues of concern included the high number of wells with inadequate well covers, with cracks in cement floors or otherwise hygienically poor. These faults could influence the potential contamination pathways, leading to the increased microbial and nitrate levels detected in water samples.

CONCLUSIONS

Groundwater is a major source of domestic water in large parts of Babati town. The contamination potentials highlighted in this study need to be addressed to ensure protection of this resource and the safety of the users. The siting of pit latrines near wells is a known potential cause of groundwater

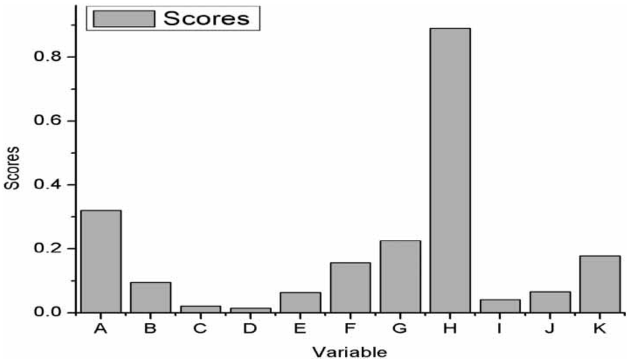

Figure 6 | Sanitary risk inspection results.

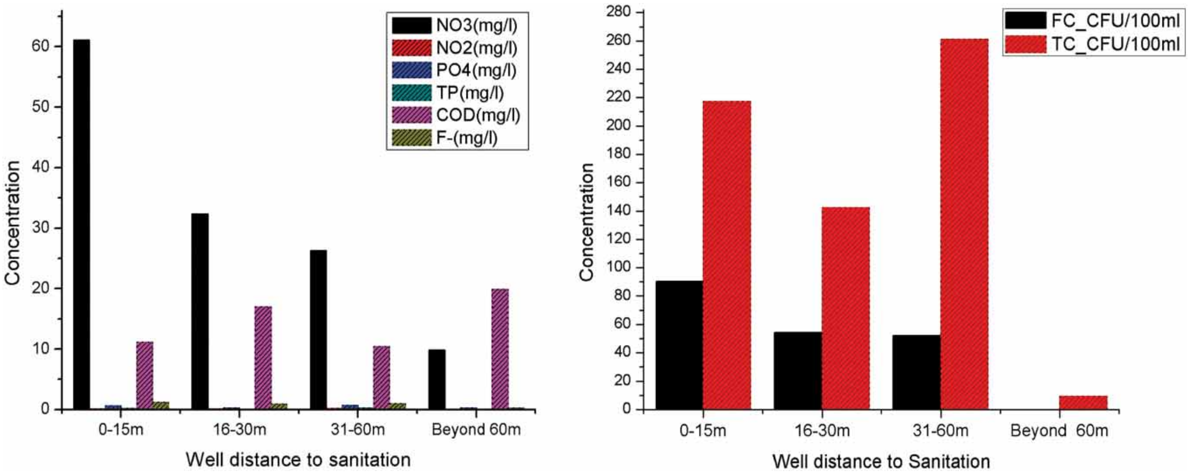

Figure 7 | Correlation of NO_3, NO_2, PO_4, TP, COD, F, and microbial concentrations against well distance from sanitation.

contamination. A remarkable number of wells, mostly unlined and without adequate covers, are near sanitary facilities that are in inadequate condition. Nitrate concentrations were very high in the shallow wells compared to the boreholes. Apart from poor well completion, the random siting of sanitary facilities near wells is an emerging water contamination threat in this small town, in which toilets and wells are placed near to each other in a high density residential area with small land plots.

While users think that their water collection/drawing methods are safe, water quality tests have revealed that the shallow wells are contaminated with both microbes (FC and TC) and nitrate. Boreholes however, are not contaminated. Well depth, proper sealing and lining and the condition of the well cover are important in ensuring provision of safe water.

The results of the study imply, therefore, that contamination is likely to increase further as the population increases, if protection measures are not taken. The community would be prudent to avoid using the shallow wells, which are the most susceptible to contamination, and to ensure that well water is boiled or disinfected before consumption. It is anticipated that the study's findings could be used as baseline information for initiatives aimed at developing understanding of the impact of current sanitary facility design and distribution, and existing regulations to minimize groundwater contamination in small towns like Babati.

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