2019-03

Risks of sanitation facilities to groundwater pollution in Babati town, Tanzania

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https://doi.org/10.58694/20.500.12479/276

RISKS OF SANITATION FACILITIES TO GROUNDWATER POLLUTION IN BABATI TOWN, TANZANIA

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A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Master's in Environmental Science and Engineering of the Nelson Mandela African Institution of Science and Technology

Arusha, Tanzania

March, 2019

ABSTRACT

Despite of its importance for human consumption groundwater resource is under threat of overexploitation and pollutions. The study to assess the risks of sanitation facilities to groundwater pollution was carried out in the small town of Babati in Manyara, Tanzania. The identification of all the wells in the vicinity of town and their proximity within 60 m radius to each recorded. Water sampling from the selected wells was done and the tests for nitrate, nitrites, total phosphorus, Phosphates, Chemical oxygen demand, fluorides and microbial (Fecal and Total coliforms) levels performed. Methods used included Diazotization, Cadmium reduction, Ascorbic acid, ion selective membrane and membrane filtration (MF) for nitrites, phosphates, fluorides and microbes respectively. Geographic information System (GIS) was used to geo-reference the water sources and water quality data were analyzed by using OriginPro8 SR0 v8.0724 software. The results revealed higher fecal coliform in shallow wells both used bucket and pumps to draw water. The maximum mean level of FC was 85.81CFU/100 mg/l and NO_3 was 65.48 mg-NO_3/l. Boreholes indicated lower nitrate levels than National and WHO standards and were all free of fecal coliforms. Other parameters were all within recommended limits for all wells tested. The evaluation of the potential contamination pathways revealed that the shallow well depth mean value was 10.40±0.30 m (N=366 $P<0.05$), 70% were unlined and 19% were uncovered. About 74% of the wells were within 30m of sanitation facilities, of which 60% were traditional pit latrines. The findings reveal that most shallow wells (64%) are polluted and the aquifer of Babati classified as a moderately vulnerable to contaminations. The results showed a very high risk in some parts of Kiongozi in Maisaka ward and some other parts in Babati and Bagara wards. Most location of the locations found with shallowest well depths also indicated the increased risk of groundwater pollution (Fig. 17). Therefore it is prudent that the community avoids relying on shallow wells and boiling of domestic water before consumption. Authority should also seek for a simple and affordable way/strategy to that will improve sanitation facility designs, distributions. Also to establish adequate regulations to overcome environmental contamination challenges, persistence pollutant chemicals and resistance antibiotics through drinking water sources in developing countries like Tanzania.

DECLARATION

I, Peter A. Pantaleo hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this dissertation report is my own work and has never been submitted to any other university for the award of similar or other degrees.

Peter A. Pantaleo____________________ **Date_______________________**

Name and signature of candidate

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CERTIFICATION

The undersigned certifies to have read and accepted this dissertation titled "Risks of sanitation facilities to groundwater pollution in Babati town, Tanzania", to fulfill the requirements for Master of Environmental Science and Engineering of the Nelson Mandela African Institution of Science and Technology (NM-AIST).

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ACKNOWLEDGEMENT

First and foremost, I thank God the creator for his protection, strength, patience and good health throughout the period of my studies and the successful completion of this program. I would like to acknowledge the Government of the United Republic of Tanzania through the Tanzania Atomic Energy Commission (TAEC) for funding my studies and the UK Aid through Department of International Development (DFID) as part of the Sanitation and Hygiene Applied Research for Equity (SHARE) Research Consortium (http://www.shareresearch.org) for their partly funding support to accomplish research work in Babati town. My sincere thanks are also extended to my Supervisors: Dr. Kelvin M. Mtei, Prof. Karoli N. Njau and Dr. Hans C. Komakech for their supervision, guidance and friendship during the preparation of this report till submission. Other special thanks are directed to the community of Babati town for their full cooperation and assistance during onsite field data and sample collection activities. I also wish to acknowledge the staff of the Nelson Mandela African Institution of Science and Technology, Dr. Revocatus Machunda for introducing me into Babati project and Mr. Paulo Sanka for his support and cooperation during the analysis of samples in the NM-AIST MEWES laboratory.

DEDICATION

This work is dedicated to my beloved parents Aloyce, J. M. and Cesilia, J. T. who raised me and gave their special care during my entire childhood's life and to my beloved wife Rehema J. Lyimo and children (Jolene and GodLove) for their patience and support for the whole period of my studies.

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LIST OF ABREVIATIONS

BAWASA	Babati Urban Water Supply & Sanitation Authority
CES	Cation Exchange Capacity
DEET	diethyltoluamide
GIS	Geographic Information System
GPS	Global Position System
MDG	Millennium Development Goal
SDG	Sustainable Development Goal
SFD	Shit Flow Diagram
SNV	Smart Development Works
TBS	Tanzania Bureau of Standards
UNICEF	United Nations Children's Fund
URT	United Republic of Tanzania
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background information

Improvements in sanitation facilities hygiene practices and access to sufficient quantity of good quality water supply are known to be important barrier of many infectious diseases. Globally efforts by governments, development organizations, and donors have been straggling to ensure access to clean water and sanitation for all as an essential part of the world to live. For instance the Sustainable Development Goal (SDGs) adopted in the New York recognizes the need for addressing issues related to clean and safe drinking water, sanitation and hygiene and the quality and sustainability of water resources worldwide (Connor, 2015). However, several researches have reported various cases of contamination of groundwater resources relied upon by local communities due to placement of water sources near onsite sanitation facilities (<10 m) (Sorensen *et al*., 2014; Wright *et al*., 2013)

Improved sanitation facilities are one of the major components that ensure separation of human wastes from human contact and the environment to reach water resources. Despite of the reported contamination cases attributed by the use of inadequate facilities, only 63% of the world population is reported to use improved sanitation facilities with 30% and 41% residing in Sahara Africa and Southern Asia respectively (WHO and UNICEF, 2012). According to UNICEF, by the end of 2011 about 2.5 billion people had no improved sanitation facilities and that the number of people practicing open defecation was about 15% of the world population (WHO and UNICEF 2012). In many cases unimproved sanitation facilities do not ensure hygienic separation of human wastes from contacts to the environment and this can cause contamination of groundwater resources by chemicals and microbial pathogens when the contained wastewater finds its pathways into the aquifers (Bradford *et al*., 2015). Consumption of contaminated water may result into a burden of disease outbreak (Bakobie and Awal, 2015; Nyenje *et al*., 2013). About 760 000 of children below 5 years of age are reported dying from diarrhea each year, mostly in the developing countries (WHO, 2013). 88% of this disease is reported to be attributed to the use of inadequate water for hygiene, unsafe drinking water and lack of access to improved sanitation (Bos *et al*., 2008.)

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 and 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 land and increase the risk of water contamination (URT and SNV, 2014). In Tanzania 23 900 children less than five years old are reported as dying each year from dysentery and diarrhea linked to the consumption of unsafe water (Elisante and Muzuka, 2016).

This study was conducted to assess the risk arising from the interaction of sanitation practices and facilities with groundwater resources in the fast growing town of Babati in northern Tanzania. The findings of this report are anticipated to contribute to the ongoing development of the town hygiene and sanitation master plan.

1.2 Problem statement

Lack of proper and adequate sewage management practices and the direct discharge of sewage into the environment are commonly reported in developing countries (Graham and Polizzotto, 2013; Han *et al*., 2015). In Tanzania for instance the only 10-25% of the rural population is reported to have access to improved sanitation facilities as per the JMP definition whereas the rest relying on un-improved pits for fecal disposal. Open defecation is also reported to be practiced in some area (URT and SNV, 2014). These practices lead to pollution of water resources. During rainy period, human wastes may end up flushed into the surface water systems whereas the poorly constructed or unsuitable placed sanitation facility may pollute groundwater resources through wastewaters seepage in the soil substrata. Studies by Nyenje *et al.* (2013) and Wright (2013) are providing a strong evidence on groundwater pollution as an attribute of sanitation facilities. Other studies also reports high levels of contamination attributed by poor sanitation facilities and practices. For instance, Sorensen *et al.* (2014) carried a study in Zambia and identified the prevalence of insect repellent diethyltoluamide (DEET) of 1.8 μg/L and chlorinated by-products trihalomethanes (up to 50 μg/L), and the surfactant 2, 4, 7, 9-tetramethyl-5-decyne-4, 7-diol (up to 0.6 μg/l) compounds in shallow wells attributed by inadequate well protection, sanitation and household waste disposal. In general, most studies on pollution of groundwater resource from sanitation focused on poor sanitation (Grönwall, 2010; Lüthi *et al.*, 2010) and the influence of these pit latrines on groundwater pollution (Mitchell *et al.*, 2016).

In Babati town, little has been done to monitor groundwater quality status in relation to sanitations. The study of pollutant load as an attribute of sanitation facilities and hydrological dynamics with seasons is an aspect that requires further research. This study intends to provide data and information related to water quality status and to develop pollution risk index and groundwater vulnerability of Babati aquifer.

1.3 Objective of the study

1.3.1 Main objective

The general objective of the study is to assess the risks of sanitation facilities and develop pollution risk index arising from their interaction with soil and groundwater in Babati town.

1.3.2 Specific objectives

(i) To identify and map current sanitation facilities and their associated environmental risks in Babati town.

(ii) To identify surface and groundwater pollution pathways in Babati town.

(iii) To assess and map groundwater quality, soil and hydro-geological characteristics of Babati town.

(iv) To develop groundwater risk index and vulnerability map.

1.3.3 Research questions

(i) What are the different types of sanitation facilities and their potential risks to environmental pollution in Babati town?

(ii) What are the possible routes of surface and groundwater contamination in Babati town?

(iii) How are the qualities of groundwater, soil and hydrogeology distributed around Babati town?

(iv) How is groundwater quality distributed in relation to sanitation facilities–soil properties and groundwater interactions in Babati town?

1.4 Research justification

Improvements in sanitation and hygiene practice and the quality of water supply remains the most important barrier to many infectious diseases. Safe hygiene practices coupled with appropriate sanitation facilities, is reported to reduce risk of becoming exposed to diseases (Butterworth and Soussan, 2001). However, poorly constructed sanitation facilities and hygiene practices do contribute to water source contamination in many urban areas (Mitchell *et al*., 2016). Pit latrines are widely used in Babati town (URT and SNV, 2014) and shallow wells as well as boreholes are the main sources of domestic water. It is therefore prudent that a study to understand the interaction of sanitation facilities and groundwater be carried in Babati. Enough data and information related to water quality status and the groundwater vulnerability of Babati aquifer are inevitable at this time the region is revising its master plan (Babati Town Council reports, 2017). One area of improvement is to consider and include hygiene and sanitation in the overall planning process. In this respect it is important to have knowledge of groundwater and geology of Babati town and the potential interaction between sanitation facilities and groundwater in order that the master planning process is informed and proper choice and location of different types of sanitation facilities conforms to the groundwater resource and soil conditions of the area.

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 their potential influence.

CHAPTER TWO

LITERATURE REVIEW

2.1 An overview of water supply, and sanitation practices and facilities

2.1.1 Sanitation

Sanitation refers to the provision of facilities and services for the safe disposal of human urine and faces. I cover issues related to drainage of storm-water and effluents, flood management, collection, disposal and removal of human excreta. Inadequate sanitation may result into a burden of diseases worldwide and therefore improvement of sanitation is significant in reducing risk impact on health in households and communities (Montoute and Cashman, 2015). According to the Millennium Development Goal (MDG) improved sanitation facility refers to the one that hygienically separate human waste from contact.

2.1.2 Water supply

Safe water supply refers to those sources which are likely to supply water which is not detrimental to health (Hamner et al., 2006). Improved drinking water sources are reported to include public taps or standpipes, tube wells or boreholes, protected dug wells, protected springs and rainwater collection (Montoute and Cashman, 2015). Worldwide 780 million people are reported to have no access to improved water sources whereas 2.5 billion lack access to adequate sanitation (WHO, 2012). Water supply and sanitation are the component which are interrelated because their improvement can protect environmental contamination and risk of diseases

2.1.3 Groundwater

Groundwater is defined is defined as subsurface water and can be either confined or unconfined aquifer water distinguished by the water components (Magesh, 2013). Water stored as ground water is originated largely from surface water that seeps slowly into the ground; it takes long time to fill up the groundwater storage (Barzani *et al.*, 2017). Groundwater is the world's largest freshwater store and the world's most important source of freshwater supplying 2 billion people with drinking water. It is also widely used for irrigation of the largest share of the world's food supply (EGU Blog).

2.1.4 Groundwater quality

Groundwater quality refers to the state of water found beneath the surface. It comprises the physical, chemical, and biological qualities of water (Harter, 2003). Groundwater quality data give important inputs to the historical geology regarding with their recharge, discharge and storage. Variation in groundwater quality is a function of their physicochemical parameters that are greatly influenced by geological formations, fluctuation of sea level rise and anthropogenic activities (Manjusree *et al*., 2009: Kumar *et al*., 2012). Most ground water is odorless, colorless and without specific taste.

2.2 Impact of sanitation facilities and practices on surface and groundwater quality

Despite of the increased reported awareness and attention to water and health worldwide still water, sanitation and hygiene challenges have continued existing in the developing world (Palaniappan *et al*., 2008). Inadequate sanitation facilities are widely reported existing due to the wide use of poorly constructed sanitation facilities including septic systems and pit latrines which are used as the main option for disposal of human wastes (Graham and Polizzotto, 2013). The major concern associated with poor sanitation facilities is their risk of causing seepages of nutrients and pathogens which may find its ways and reach surface and groundwater resources and render it unsafe for human consumption (Oluseun, 2013). Consumption of such contaminated water often results into incidences of waterborne diseases such as diarrhea, which is reported to account for nearly 760 000 deaths of children under 5 years every year (WHO, 2013). Studies conducted to evaluate effects of poor sanitation facilities have revealed several cases in which pit latrines were the main causes of groundwater contamination. For instance study conducted in the peri-urban area of Kisumu, reported to have identified positive thermotolerant coliform and nitrates values above World Health Organization limits of 10 mg/l in groundwater samples obtained near pit latrine (Wright *et al*., 2013). This was an indication that the pit latrine construction near the water sources increases the ability of pollutants to enter the water resources and cause contamination. Similar research conducted in one slum in Kampala also reported significant groundwater pollution by nutrients from pit latrines (Nyenje *et al*., 2013). In the study by Nyenje, the dissolved nutrients and the processes likely to affect them were assessed.

Other investigations that have reported the contamination of water resources include that of Sorensen *et al.* (2014) on “emerging contaminants in urban groundwater sources in Africa”. In this study up to 1.8 mg/l of insect repellent DEET was detected in groundwater samples obtained from shallow wells found in low cost housing areas associated with poor sanitation infrastructures, inadequate waste disposal and well protection in Zambia. The study by Megha *et al*. (2015) in Southern India also found groundwater in the village microbiologically unfit for consumption due to several factors including improper placement of wells near pit latrines. Total coliform count and fecal coliform count were found to increasing as the distance of the well to latrine decreased (Megha *et al*., 2015).

2.3 Fecal sludge Management

Fecal/shit sludge (FS) refers to onsite sanitation technologies including pit latrines, un-sewed public ablution blocks, septic tanks, and dry toilets, which has not been transported through a sewer (WSP, 2016). Fecal sludge management includes the storage, collection, transport, treatment and safe end-use or disposal of fecal sludge. This approach aims to obtain relevant information to develop a diagram (Shit/fecal sludge diagram). Shit flow diagram (SFD) is the diagram that presents a clear picture of the outcome arising from wastewater and fecal sludge management practices and services in a city or town in terms of percentage of population (Blackett *et al*., 2015).

Shit/ Fecal sludge waste flow diagrams which have been developed in some cities to show the city-wide picture have identified poor management of fecal sludge in some cities. According to WSP 2016, in Lima about 64% of the fecal sludge is reported not effectively managed although 95% of fecal waste is removed from domestic environments. While 92% of the households have sewer connection the analysis has indicated that 50% of waste water is lost through leakages to the environment (WSP, 2016). In Dar es salaam city the shit/ excreta flow analysis and the SFD developed has revealed that 90% of inhabitants depend on onsite sanitation and 57% of the sludge produced is directly introduced into the environment without treatment whereas 43% is well managed by either safely containment on site or safely dispose in the recommended safe environment (Blackett *et al*., 2015).

Several researches have been done to asses impact of sanitation systems and management of fecal sludge on groundwater resources (Shivendra and Ramaraju, 2015; Klinger *et al*., 2002). Several methods including the investigation of chemical and microbial loads and the assessment of volume and characterization of fecal sludge produced, the pit emptying practices and the risks of pit contamination of groundwater have been conducted to determine the relationship between potential risk factors for groundwater contamination due to the use of inadequate sanitation facilities and poor management of fecal sludge. In this study combined methods to assess soil, groundwater quality parameters and their interaction with sanitation facilities in the town will be conducted. The shit/fecal sludge management survey within the Babati town will consequently be done and using a questionnaire to find out the information related to faecal sludge management and the associated environmental contamination risk to impact groundwater resources. The pre-set questions to extract information related to availability of toilets, type of sanitation facility owned, practiced defecation (for those who had no toilets), disposal methods etc. The aim was to understand the risk the associated with current fecal sludge management and disposal practices have on water resources contamination and the surrounding nearby environments.

2.4 Soil and its influence on contaminants' transport

A soil as the upper weathering layer of the solid earth crust has properties varying from place to place depending on the underlying bedrock composition, land uses and other human activities. However, the release of pollutants on land can lead into a changed soil properties. For instance application of pesticides or other chemical contaminants on soils can affect soil fertility and productivity as can lead to a reduced soil quality, its functions and the whole process of microbial community (Černohlávková, 2009). The pathways of contaminants through the soils may take place as an aspect of several processes including direct filtration, sorption of contaminants on mineral grains and soil organic matter, bio- degradation by soil microorganisms and geochemical reactions (Rockhold *et al.*, 2004). To understand the impact of soil on contaminants transport it requires an understanding of soil properties and their fate on contamination in subsurface environment. Soil properties like pH (acidity), texture, amount of organic matter may influence pollutants/pathogen movement in the soil. For example soil pH is known to favors virus and microbial adsorption. For instance low pH caused virus adsorption and the high pH values results into elution of adsorbed viruses (Davis *et al.*, 2006; Hong *et al.*, 2011). Soil texture is defined by the soil types (clay, silts and sands) which may play different roles on contaminant transport. Clay soil has effects of making soil sticky and able to retain water and contaminants. Silts on the other hand make the soil slippery while sand soil causes loose structures which may influence fast movement of pathogens. Amount of organic matter may lead to a competition with organisms for adsorption sites on the soil particles and resulting to a decreased adsorption of viruses (Hilliard and Reedyk, 2014) already adsorbed and Cations influences pollutant mobility and uptake whereby soils with high Cation Exchange Capacity (CEC) indicate more retention of nutrients in the soil and reduced mobility.

2.5 Pollution risk index

Pollution risk index is the way of representing hydrogeological information with a simple map that can easily be used in water management process. The approach methods developed to assess groundwater vulnerability and index are categorized into index-and-overlay, process based computer simulation and statistical analyses (Haouchine *et al.*, 2015, Harter and Walker, 2001). Index and overlying is a method which rely on combining maps patterning the physiographic attributes of geology, soil, aquifer media and depth to water which controls groundwater vulnerability of the area. Each attribute is normally used to determine the degree of vulnerability (Rizka, 2018). To develop an interaction index these information are often interpolated using GIS software capable of overlaying maps pertaining these information. Through Geographic Information System (GIS) an overlay of various properties of the soil, sanitation facility types and water recharge information can be used to show their variations. Apart from index-and-overlay the statistical method is another category of the methods used to quantify the risk of groundwater pollution by comparing the relationship between environmental conditions and the observed human activities on the environment likely to be potentially sources of contamination. In this method the statistical analysis is used to establish the relationship and the statistical significance are calculated. Process –based computer simulation is a third method for vulnerability assessment and it involves computer simulation model.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area description

The study was conducted in Babati, Manyara region, Tanzania, latitude 4^{0} 12' 28.18" S, longitude 35^{0} 44' 46.13" E, and elevation 1392m above sea level. In 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 that is characterized by a rainy season lasting roughly from October to May and a dry season between June and September (Ströomquist and Johansson 1990)

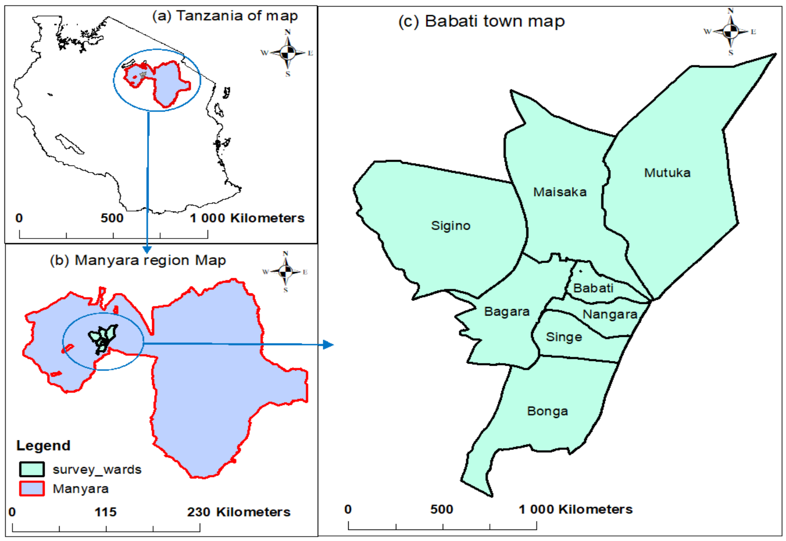


Figure 1: Map of Babati showing the location of town wards

3.2 Identification and mapping of sanitation facilities the associated environmental risks

3.2.1 Data collection

(i) Identification of water sources and sanitation facilities

The groundwater sources and sanitation facilities were surveyed in all wards of Babati town to evaluate their condition and their proximity to each other. Geographic Positioning System (GPS) device was used to record the location for each water source and sanitation facilities and mapping of their distribution was generated by using ArcGIS 10.3 software. Sanitary risk inspection for each water source was conducted by a checklist as per variable questions (Table1). Other collected information includes well depth, sanitation types, sanitation depth, disposal options and the emptying frequencies. Groundwater level in wells was measured using Geotech water level meter capable of detecting up to 100m depth to water.

Table 1: List of questions for sanitary risk inspection for groundwater sources

A	Is there a pit latrine near the well within 10m?	Yes/No
B	Is there any dumping yard for animal and or domestic wastes within 10m of the well?	Yes/No
C	Is there any pond of standing water around the concrete floor of the well	Yes/No
D	Is there a surface water found within 10 m to the well	Yes/No
E	Is there a pit latrine on higher ground than the well?	Yes/No
F	Are there cracks on cement floor surrounding the well?	Yes/No
G	Is the cover of the well in adequate cleanness	Yes/No
H	Are there other latrines within 30m of the well?	Yes/No
I	Are there any uncovered wells within 30 m of the wells/borehole	Yes/No
J	Is the concrete floor les that 1m around the well	Yes/No
K	Is there inadequate fencing around which might permit animals in?	Yes/No

3.2.2 Contamination pathways for water sources

(i) Soil sampling

In order to obtain a composite soil samples the areas of similar characteristic were selected for sampling. The selected soil characteristics included the slopes, drainage near Lake Babati, highlands and lowland areas. In order to determine the soil textural properties as the depth increases and also to avoid erroneous results soil samples were taken in I m depth from each sampled areas/point.

In the field the sampling was done using Auger instrument which provides a continuous soil core with minimal disturbance. Both surface and subsurface soil were tested and therefore, the sample cores were collected from the top, at 0.5m and at 1m) and the soil from each core depth were thoroughly mixed in a plastic containers. Samples were packed and labeled for laboratory analysis of particle size distribution

(ii) Laboratory analysis for Soil pH and particle size distributions

Pipette method as per Ketler *et al.* (2001) was used to determine soil particle size distributions. 10gm of soil sample was added into 100mL of distilled water and centrifuged by “Eppendorf AG 5810” instrument for 10minutes at 1500 rotations per minutes to separate from other particulate organic matters (POM). Boiling of the sample was done to evaporate the excessive water and hydrogen peroxide (H_2O_2) was used to remove organic matters present in the soil. Calgon (a solution of sodium hexa-meta-phospahte and sodium carbonates) was used to facilitate the separation process. The 106 µm pore size sieve was used to separate sand and distilled water to wash the silt and clay out of sand. The obtained portion of sand soil was dried at temperature of 105^0C in a separate and tarred beaker. After dryness the weight for sand was recorded.

The separation of silt and clay from the sample was made from the suspension. The suspension was diluted to a volume of 1000 ml using distilled before equilibrated overnight in a water bath. Thoroughly stirring was done and immediately 25 ml was drown to a depth of 10cm and dried in a separated and tarred beaker at 105^0C to obtain the weight of silt and clay after dryness. Twenty five milliliter (25 ml) of sample was drown at a depth of 10cm after 4hrs settling time in a 20^0C sample temperature and dried at 105^0C. Percentage sand, silt and clay composition was obtained through calculations as per Kittler *et al*. (2001) method. Soil pH was determined by thorough mixing of distilled water and soil sample at a ratio of 1:3 respectively. HANNA instrument model HI99121 was used to read the soil pH values.

3.2.3 Evaluation of water sources constructions, management/operation process and the condition of the surrounding areas

The water sources were evaluated to determine source management condition of the source to prevent the interaction with the contaminant from the surrounding area to enter the sources. Assessment of springs and wells constructions/finishing and activities taken place nearby each were assessed. During the assessment the information related to well depth, well lining, depth to water, well cover hygiene and the water collection method used to draw water from the source were collected. For sanitation facilities, the survey was conducted to determine their physical condition, types and their threat may pose on well water contaminations. The questionnaires appended (Appendix 1 and 2) were used during the survey.

3.3 Water quality assessment

3.3.1 Groundwater sources

The classification of the sources was assessed and sampling well groups formulated on their depths and the methods used to draw water. These groups included the shallow wells below 30 m and boreholes above 30 m, in which electric/hand pump was used to extract and those buckets used (Fig. 2).

Figure 2: Wells showing the methods of water collection from the source

3.3.2 Surface water and springs

Each surface water and spring sources used for domestic purposes in Babati town were justified and sampled for assessment. Sampling was done at the catchment where the water was withdrawn.

3.4 Water sampling and Laboratory analysis

3.4.1 Onsite sampling and data collection

A clean stainless steel container with the aid of a rope was used to collect water samples from each well (Fig. 3) and transferred into a sterile plastic container and sealed. The sealed containers were labeled and placed in a cool box with < 4^0C and transported into the laboratory for analysis. To avoid contamination the rope was used once and the new rope was used for the collection of sample from the next source. Seventy percent (70%) ethanol was used to sterilize the containers before rinsed using distilled water and the preservation of samples for nutrient was done by the addition of conc. Sulphuric acid until the sample attained a pH of 2.0. In-situ measurements for Conductivity (EC), total dissolved solids (TDS) and Dissolved oxygen (DO), pH, Temperature and turbidity were done using Palintest®) Macro 900 Meter while turbidity was determined using microprocessor instrument (HANNA HI93703). A sanitary inspection for each source was done using a checklist as per the variable questions in Table 1. The risk scores were assessed based on Yes or No ratios of which the higher positive responses indicated a greater risk of contamination.

Membrane Filtration Method (MF) was used to determine microbiological contents for fecal coliform bacteria and total coliforms (TC) in water. A Palintest kit (Wagtech 2) capable for site sterilization, filtration and incubation was used. 50 ml of each sample was filtered through 0.45 micron membrane filters using sterilized vacuum filter. Sterilized forceps were used to remove the filter from the vacuum holder and place them in a pre- labeled Petri dish contained Membrane Lauryl Sulphate Broth base. The dishes were incubated for 18 hours using Wagtech incubators in temperatures of 44.5^0C and 37.0^0C for fecal and total coliforms bacteria respectively. Counting of the viable colonies was performed using a lens.

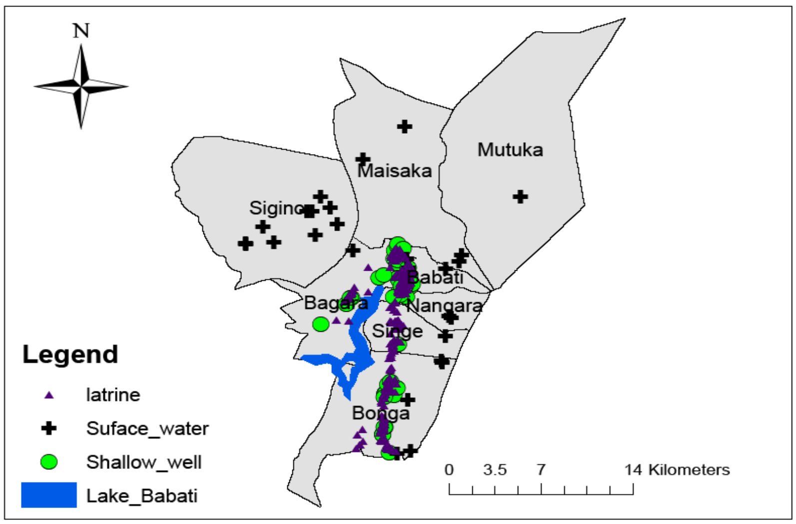


Figure 3: Sampled water source locations and near latrines within 60m

3.4.2 Laboratory 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 vials and the methods are USEPA accepted for water analysis using Hach methods**.** Chemical oxygen demand 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.

3.5 Water pollution risks

The assessment of groundwater pollutions and the development of index (aquifer vulnerability index Vi) was performed using overlay indices based on DRASTIC method by Aller *et al*. (1987) involving evaluation and scoring systems of seven hydrologic characteristics of the study area. The term DRASTIC represents the combination of seven parameters including the depth (D) to water, net recharge (R), Aquifer media (A), Soil media(S), Topography/elevation(T), Impact of vadose zone (I) and hydraulic conductivity (C) of the aquifer. The information related to the above parameters was gathered from the study area and mapping of their rated attributes was done using ArcGIS 10.3 software. The ranging rate for the DRASTIC factors varied from 1 to 10 depending on its ability to limit the contamination of groundwater resources. The rated values were thereafter combined to develop risk index using equations:

$$VI = Dr * Dw + Rr * Rw + Ar * Aw + Sr * Sw + Tr * Tw + Ir * Iw + Cr + Cw \quad \text{.......1}$$

Where r = rating and w= assigned weight.

The equation may however be reduced to

$$Vi = 5Dr + 4Rr + 3Ar + 2Sr + 1Tr + 5Ir + 3Cr \quad \text{.......2}$$

(Aller *et al.,* 1987). The vulnerability values were categorized such that the lowest vulnerability value corresponds to the index values less than 79 was described by the index values greater than 200 (Haouchine *et al*., 2015)

3.5.1 Data inputs in DRASTIC method

Depth to water (D): The evaluation and rating results for depth to water was performed during the assessment of the risk to groundwater resources. The data considered the well depth to water obtained from among 435 measured boreholes and shallow wells around Babati town. The information of well depth to water is important because it determine the length through which contaminant can travel to reach the aquifers. Increased depth to water is associated with greater attenuation because it incurs longer travel time of contaminants.

Net recharge (R): Net recharge refers to the amount of water that penetrates and reaches the water table. This water acts as carrier of contaminants to move from the source point to the groundwater. Rainfall data were used to generate maps and a combination factor of soil, elevation and rainfall were used to generate the net recharge factor. The evaluation of the net recharge is important because the recharge between confined and unconfined aquifers differs. The areas with unconfined aquifers, the recharge occur more readily resulting into a greater pollution potential than in the areas of a confined aquifer which are partially protected by a layer of low permeability media which retards water movements.

Vadose zones (I) and the Aquifer media (A): The evaluation and rating results for these parameters were evaluated. The information were obtained from BAWASA drilling datasheets of 6 boreholes currently under operation and the laboratory particle size test results were used to generate the rating values and the development of maps. This parameter corresponds on the rock type formation and the geology of Babati which was obtained from the department of Geologic Survey of Tanzania.

Soil media (S) refers to upper weathering layer of the solid earth crust characterized by significant biological properties. Soil media vary from place to place depending on the underlying bedrock composition, land uses and other human activities. Soil has a significant impact on both lateral and vertical water movement and hence the ability of contaminant to move into the vadose zone. The pollution potential of the soil is largely affected by the type of the soil. Fine silts and clays have larger surface area which makes it higher in water holding capacity leading to have less pollution potential as to compare with sand soil. Data were obtained from the lab and the additional from the ministry of Agriculture, Food Security and Cooperatives

Topography (T) refers to the slope of the surface and other observable features. Topography influences the rate of infiltration of water from rainfall, snowmelt or irrigations. It is one of the important parameter since it determines the amount of runoff as well as the supply of water to the soil profile. For instance the steep slope reduces the rate of infiltrations because it speed up runoff and have reduced retention time for water to infiltrate. In flat surface/plains the water retention is greater leading to have a long time enough for water to infiltration. Therefore the locations with higher infiltration rate have also high chance of pollution potential. The slope map was developed using the elevation data collected around Babati town. Rating range was from 1 to 10 and the flat slopes locations were classified as more risk areas and was assigned higher scores.

Hydraulic conductivity (C) refers to the ability of the aquifer material to transmit water. It describes and controls the rate at which water will flow under a given hydraulic gradient. Due to the lack of hydraulic conductivity data of the aquifer, the value were taken from previous research based on type of aquifer media (Massawe *et al*., 2017).

Table 2: The assigned ranking rate for the DRASTIC factors (Allar *et al*., 1987)

S/N	Parameter	Range	Assigned Rate	Weight
1	Depth to water (m)	<5	10	5
		5 to 10	7	5
		10 to16	5	5
		16-25	3	5
		25to 33	2	5
		> 33	1	5
2	Net recharge (cm)	<5.08	1	4
		5.08-10.16	3	4
		10.16-17.78	6	4
		17.78-25.4	8	4
		> 25.4	9	4
3	Aquifer media	Quartzite	2	3
		Granite	3	3
		Schist	6	3
4	Soil Media	Sand	9	2
		Clay loam	3	2
		Silt loam	4	2
5	Topography (%)	<2	10	1
		2.0- 6	9	1
		6.0-12	5	1
		12.0-18	3	1
		>18	1	1
6	Impact of vadose zone	Quartzite	2	5
		Granite	3	5
		Schist	6	5
7	Conductivity	Quartzite	2	3
		Granite	3	3
		Schist	10	3

3.6 Data analysis

Descriptive statistics was used to correlate the determined mean values against well distances from sanitation. The groundwater quality parameters represented are the mean concentrations and the standard errors of the mean (M±SEM).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Sanitation facility- 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 Figures 4 and 5. 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) 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). Bagara and Babati wards had 44 and 82 types of these toilets near the water sources respectively. 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.

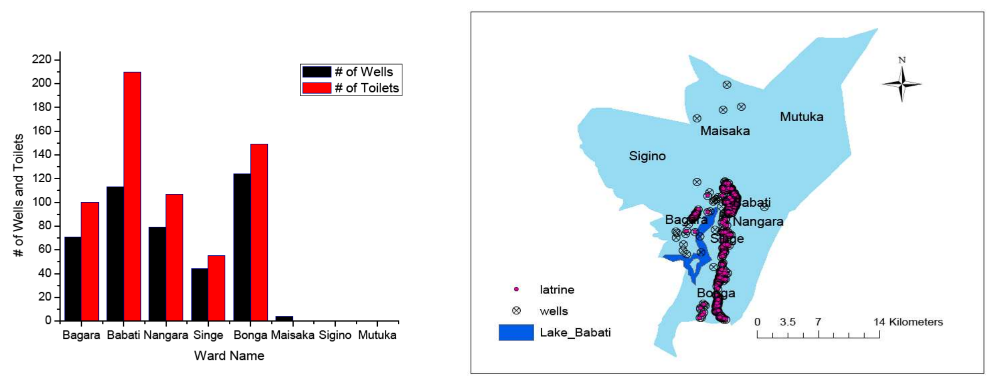


Figure 4: Number of wells and sanitation distribution at a radius of 60 m per ward

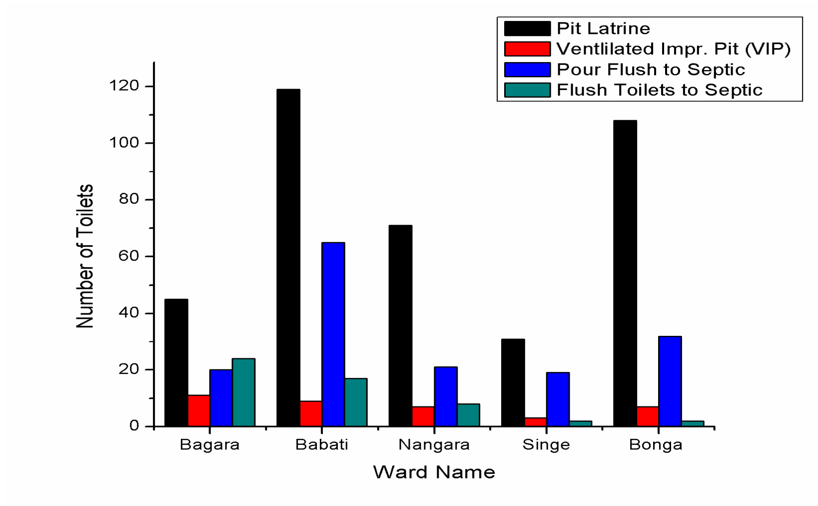


Figure 5: Sanitation types at 60m radius to groundwater sources per ward

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 the local government authorities as well as the responsible utility companies are reported to contribute to the problem in towns (Seetharam, 2015). Effluent release from poorly designed toilets on the environment increases the risk of groundwater contamination as it can find its way through the soil to reach the water table. Therefore the observed proximity of water sources to these types of toilets needs to be addressed to protect groundwater from pollution. To control contamination from these sources, 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.

4.2 Groundwater sources distribution

The groundwater source distribution is shown in Fig. 6. 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 9m (N = 366). All of the boreholes, which were mostly operated by BAWASA, were more than 70 m deep.

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 water 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 type comprising 277 (62%) of sources. BAWASA boreholes were dominant in Babati (6), Bagara (5) and Nangara (4) wards as compared with others (Fig. 8). Boreholes were all operated by the aid of pumps to draw water from the source (Fig. 7).

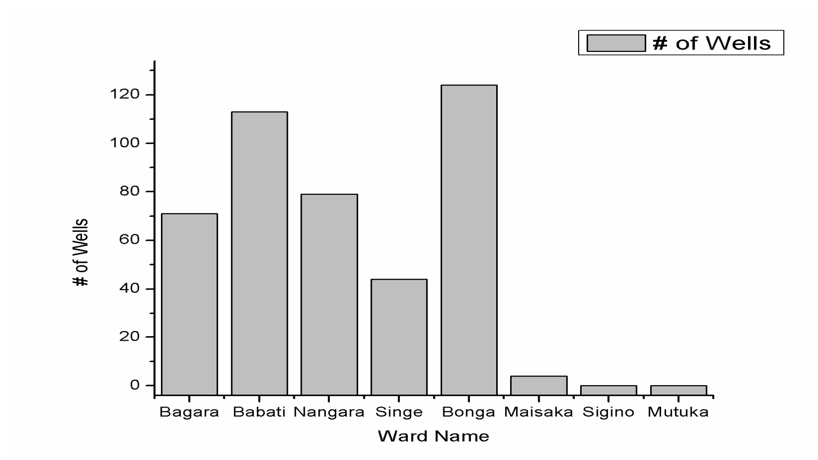


Figure 6: Groundwater source distribution by ward

Figure 7: Hand pump and Manual water collection methods

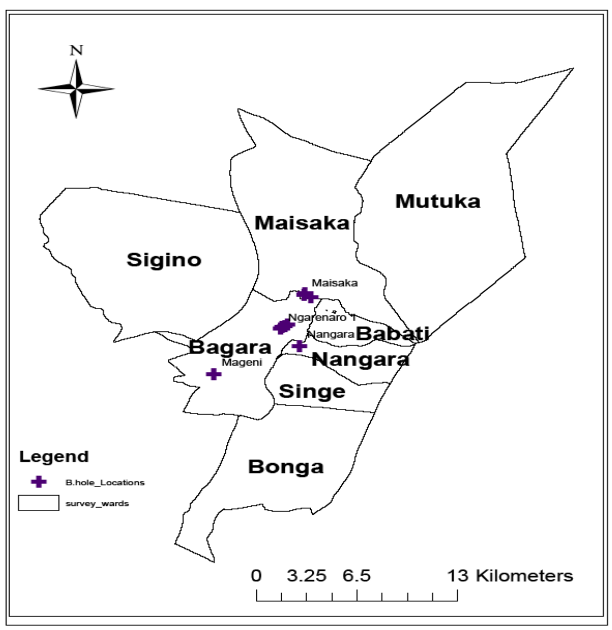


Figure 8: BAWASA boreholes active locations

Sanitary risk inspections: The sanitary risk inspection score of each ward is shown in Fig. 9. The assessment was based on the yes/no ratio of the variable (Table 1) whereby higher positive responses indicate a greater risk of nitrate. The result showed that sanitation within 30 m of wells was the leading risk, 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 (Fig. 10). The nitrate and fecal coliform data shown 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.

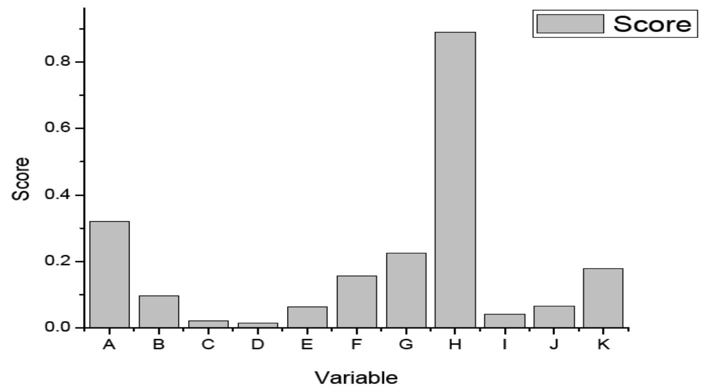


Figure 9: The sanitary risk inspection results

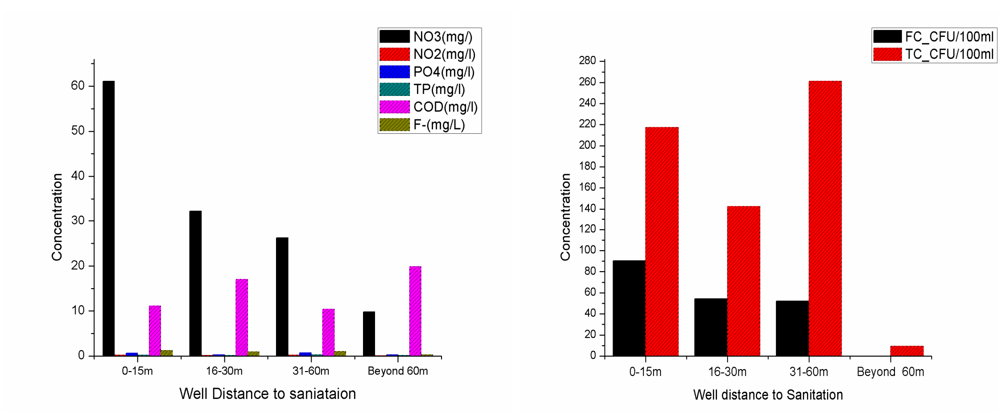


Figure 10: Correlation of NO_3, NO_2, PO_4, TP, COD, F, and microbial concentrations against well distance to sanitation

4.3 Soil test results

The results for soil texture are as shown in Table 3. Based on these results clay and silt were the dominant soil types in the sites of Babati town. Soil texture plays role in soil water retention capacity. Fine soil is defined by higher silt and clay soil composition and coarse soil is defined by larger sand composed soils. Fine silts and clays have larger surface area which makes it higher in water holding capacity and strong absorbance of pathogens and filtration of larger microorganisms to render the probability of reaching groundwater resources above 5m depth beneath the ground (WHO, 2006). Soil pH results indicated values ranging from 5.78 to 8.51. Soil pH is known to favor virus adsorption at low pH values and higher pH results in elution of adsorbed microbes. The resulted range recorded is known to be favorable for most of microbial pathogens to survive in soils resulting into their adsorption (Cho *et al*., 2016). For instance most of bacterial pathogens tolerate this pH range detected in the soil which is reducing the threat of pollutant transport through the soil. Through seepages is also minimal because of soil texture composition which is associated with high ability to retain water and the adsorption of microbes to reach the water resources to contaminate. Contamination of water sources at the study area is highly being associated to occur from the intrusion/interactions of water from nearby contaminated sources and, inadequate water sources management and well-head hygiene and intrusion of contaminated rainwater into the sources during the storm.

Table 3: Soil sampling sites and locations and laboratory results for pH and textural distribution

Sites	Site Name	Soil depth (cm)	pH	GPS Location	%Sand	%Silt	%Clay
1	Nang ziwani	Surface	7.60	E. 36'804653"	9.75	58.11	31.99
		50 cm	8.51	Utm. 9531102	2.28	69.43	28.40
		100 cm	8.34	Elev. 1354	0.90	63.45	35.04
2	Hangoni A	Surface	6.84	E. 36'805958"	39.27	17.77	39.75
		50 cm	6.78	Utm.9531982	38.63	17.99	46.11
		100 cm	6.73	Elev.1364	33.56	14.61	49.80
3	Maisaka A	Surface	7.44	E. 36'805101"	10.19	51.66	40.67
		50 cm	7.41	Utm.9535360	8.90	48.64	39.47
		100 cm	7.72	Elev.1330	18.98	56.33	24.16
4	Bonga	Surface	6.35	E.36'805566"	26.48	17.72	55.54
		50 cm	5.78	Utm.9522703	21.35	17.99	59.82
		100 cm	6.38	Elev.1416	29.40	21.53	47.07

The results of the well types and contamination pathways are shown in Table 4 while Table 5 is showing surface and spring sources management status;

Table 4: Well types and contamination pathways

Well depth(m)	**No of sources**	**No. uncovered**	**No. unlined**	**Well water Pulled manually**	**Remarks**
≤5	59	15		56	
>5 to 30	307	66		214	
>30	20	0	0	0	Pump used
Unknown	49	0	No information	0	Wells found sealed
Total	**436**	**81**	About 70%	**270**	

Table 5: Surface and spring sources management status

Water source	**No. of sources**	**Sources used after treatment**	**Sources untreated**	**Remarks**
Springs	16	1	15	Water collection in untreated sources was made directly from the source manually
Rivers	10	0	10	Water collection in the untreated sources was made directly from the source
Lakes	1	0	1	Water collection in the untreated sources was made directly from the source
Total	**27**	**1**	**26**	

Table 6: Summary of surface and spring sources information and GPS locations

Code	Source common name	GPS location			Ward	Street
		Easting (36m)	Northing (UTM)	Elevation (m)		
SW1	Dawari spring	805946	9518279	1446	Bonga	Dawari
SW2	Mirambi spring	805756	9522564	1424	Bonga	Himiti
SW3	Chemchem kwa Mussa	804924	9518014	1398	Bonga	Dawair
SW4	Mrara source	808677	9533521	1567	Babati	Mrara
SW5	Khufo water source	809885	9534698	1582	Babati	Wangwaraay
SW6	Mutuka spring	814372	9539550	1286	Mutuka	Mutuka
SW7	Hillo forest water source	809686	9534181	1596	Babati	Wangwaraay
SW8	River maisaka B	805723	9534411	1330	Babati	Maisaka B
SW9	Maisaa forest source A	808389	9525644	1580	Singe	Managati
SW10	Maisaa forest source B	808317	9525785	1538	Singe	Managat
SW11	Bonde la Hangoni	805401	9532665	1352	Babati	Hangoni A
SW12	Majengo spring	808624	9527885	1461	Singe	Managati
SW13	Mto Imbilili	798541	9538353	1329	Sigino	Imbilili
SW14	Mto Imbilili down stream	799925	9538651	1217	Sigino	Imbilili
SW15	Kwa Sombii Source	794807	9537110	1536	Sigino	Daghailoy
SW16	Waangbay river originating from Logia	795629	9535793	1486	Sigino	Daghailoy
SW17	Komoto river	801638	9535074	1341	Sigino	Daghailoy
SW18	Bonde la daghailoy	798790	9536380	1351	Sigino	Daghailoy
SW19	Singu River	793480	9535726	1625	Sigino	Daghailoy
SW20	Daghailoy spring -darajani	800450	9537311	1282	Sigino	Daghailoy
SW21	Spring kwa mzee ISSA	798145	9538375	1359	Sigino	Daghailoy
SW22	Naizori Endasago river opposite R.Singu	793506	9535656	1625	Sigino	Daghailoy
SW23	Kwere Spring	805854	9533607	1333	Babati	Kwere
SW24	King River	805591	9545486	1090	Maisaka	Kiongozi
SW25	Malangi Source 1	802447	9542733	1140	Maisaka	Malangi
SW26	Baloa source	808909	9529533	1542	Nangara	Arri

4.4 Evaluation of water sources

The results for groundwater sources and contamination pathways and for surface water and spring sources management status are shown in Table 4 and Table 5 above. Based on the results about 19% (81) of the well were uncovered and or had inadequate hygiene covers and 70% were unlined (Fig. 11). Municipal faecal sludge disposal was done in inadequate area designated in Maisaka. This was due to have un-existing municipal waste water collected pipe/sewer and treatment site. The dominated water collection methods from the wells were pumps and manually operated rope and bucket (62%) systems. Pollution of water sources from nearby pollution sources in association with inadequate waste disposal of human wastes/fecal origin or manure have been reported to exist in some cases (WHO, 2008) . In these cases the pollution detected in well water were linked with manure from the nearby farm facilitated by rainwater intrusion and nearby pit latrines respectively. The findings of all wells uncovered and/or un-lined together with the current practiced well sitting near the toilets, their shallowness and inadequate water collection methods are increasing the risks of groundwater contamination. The untreated fecal sludge disposed at Maisaka site is also an emerging risk for groundwater contamination because they might be re-transported into the water sources by flowing storm water and or creatures/pets roaming around the dumpsite (Fig. 12). About 12% (51) of sources of wells had a depth of less than 5m and are considered more susceptible for contamination the interaction with nearby toilets raised during rainfall and raised water table or from other contaminants on land surface.

Figure 11: Well unlined and with inadequate cover

Figure 12: Dumping of fecal sludge in a designated area in Maisaka

4.5 Groundwater quality

4.5.1 Onsite physical-chemical parameters

Table 7: Mean values (±) STD error of the mean for onsite physicochemical parameters in groundwater

Well types	Water extraction method	E.C (µScm-)	TDS (mg/L)	Temp (^{0}C)	pH	Salinity (PSU)	Turbidity (FTU)
Shallow	Hand/Elect Pump	919.75±114.40	598.42±73.99	24.89±0.68	7.17±0.10	0.41±0.06	1.35±0.78
	Manual Extraction	870.48±88.51	563.38±57.70	23.46±0.67	7.14±0.04	0.39±0.05	1.19±0.64
Boreholes	Hand/Elect Pump	1068.50±93.33	693.67±60.59	24.90±0.60	7.38±0.07	0.48±0.05	0

4.5.2 Laboratory results

Table 8: Mean ±STD error of the mean values of physicochemical and microbial composition in wells against water collection methods

Well types	Water extraction method	NO_3 (mg/L)	NO_2 (mg/L)	PO_4 (mg/L)	TP (mg/)	COD (mg/L)	F- (mg/L)	FC (C/100mL)	TC (C/100mL)
Shallow Wells	Hand/Elect Pump	65.48±20.67	0.19±0.06	0.68±0.07	0.21±0.02	7.40±3.00	1.09±0.08	58.50±21.43	220.83±43.27
	Manual Extraction	45.07±13.43	0.15±0.05	0.52±0.08	0.16±0.02	14.61±3.12	1.16±0.14	85.81±13.46	199.03±29.61
Boreholes	Hand/Elect Pump	9.83±4.73	0.06±0.04	0.30±0.08	0.09±0.03	19.88±3.32	1.28±0.23	0	9.33±9.33

4.5.3 Surface water quality

Table 9: Laboratory and onsite results for surface and spring water

Code	Temp (^0C)	pH	Turb. (FTU)	E.C (µS/cm)	TDS (mg/L)	Sal. (PSU)	FC (C/100mL)	TC (C/100mL)	NO_3^- (mg/L)	NO_2^- (mg/L)	PO_4^{-3} (mg/L)	COD (mg/L)	F- (mg/L)
Sw1	17.40	8.47	59.00	128	83	0.04	14	80	4.50	0.04	0.19	37	0.87
Sw2	22.90	7.39	0.00	502	326	0.21	16	116	9.60	0.09	0.28	20	0.32
Sw3	21.60	6.46	0.00	157	102	0.05	290	420	3.10	0.01	0.12	0	0.16
Sw4	16.35	8.47	0.00	262	170	0.08	42	50	3.80	0.02	0.22	0	2.01
Sw5	19.80	8.46	13.78	412	267	0.13	46	70	3.90	0.01	0.28	17	2.14
Sw6	25.00	7.62	0.00	552	358	0.23	16	320	3.90	0.02	0.16	0	0.76
Sw7	17.05	8.41	1.26	351	228	0.11	60	78	2.90	0.01	0.35	0	2.21
Sw8	23.78	8.30	11.02	883	573	0.37	340	560	14.10	0.08	0.29	58	1.78
Sw9	19.93	6.72	0.00	140	91	0.04	0	66	2.20	0.01	0.09	0	0.15
Sw10	19.20	8.24	0.00	85	55	0.03	0	44	3.00	0.01	0.16	0	0.16
Sw11	22.10	7.55	0.00	1433	931	0.68	156	630	4.60	0.01	0.09	13	1.41
Sw12	22.10	7.16	2.68	352	228	0.11	180	550	15.00	0.12	0.53	14	0.38
Sw13	25.90	7.00	0.00	565	367	0.24	0	20	17.90	0.01	0.20	0	1.29
Sw14	23.70	7.20	1.01	758	492	0.32	64	670	8.70	0.07	0.20	10	1.92
Sw15	21.80	7.96	1.53	169	109		38	440	4.10	0.01	0.22	0	0.52
Sw16	21.30	7.92	0.00	262	170	0.08	196	410	3.60	0.01	0.41	0	0.36
Sw17	23.80	6.91	2.67	612	397		18	36	4.70	0.01	0.40	0	0.99
Sw18	22.80	7.62	0.00	450	291	0.14	315	380	2.60	0.02	0.91	0	0.90
Sw19	19.10	8.30	0.00	317	206	0.10	78	170	2.80	0.02	0.54	0	0.35
Sw20	23.30	7.28	0.00	839	545		22	112	6.20	0.03	0.39	0	1.56
Sw21	23.20	6.73	0.00	459	298	0.15	0	18	9.10	0.06	0.25	4	0.92
Sw22	21.30	8.19	0.00	181	117	0.06	88	116	2.70	0.01	0.39	1	0.34
Sw23	24.00	7.20	0.00	688	447	0.29	84	330	11.10	0.06	0.17	37	1.81
Sw24	20.90	8.02	0.00	1036	693	0.49	26	96	1.90	0.01	0.26	13	3.32
Sw25	26.48	7.39	0.00	825	535	0.35	54	98	6.50	0.01	0.11	0	1.78
Sw26	22.58	8.26	0.62	513	334	0.22	10	54	3.10	0.05	0.36	13	1.42

The mean concentrations for onsite tested parameters are presented in table 7 and 9. The statistical correlation results for Electric conductivity (EC), Total dissolved solids (TDS), pH, temperatures and salinity showed a significance difference (P<0.05) between the wells types relative to water collection methods with exception for turbidity results which showed a none significance variations (P>0.05)for the shallow well and significant variation for the boreholes tested. The mean value distribution for EC, TDS, PH, temperature, salinity and turbidity were none-uniform among well types versus water collection methods. However the mean concentrations of the tested parameters were higher in the boreholes compared with exceptions of low turbidity detected. The variation and the determined concentrations were associated with location of the sources and the nature of the composed metamorphic bed rock minerals in which the sources were positioned. According to the WHO the palatability of water is considered good when the TDS value is below 600 mg/l and unpalatable when the concentration exceeds 1000 mg/l. Turbidity maximum mean value obtained was 1.35 FTU which is within WHO standard limits of 5.0 FTU. The variation of turbidity values determined in groundwater was attributed by the means of water collection and the hygiene of water well head covers which could be the possible sources of dust additions by water retuning back during withdrawal by buckets and or when opening unclean well covers. For surface water, only turbidity showed a non significant variation and all other parameter shown significant variations.

Nitrates: The mean values results for nitrates in groundwater and surface water sources are presented in Table 8 and 9, respectively. The statistical test results showed a significant variation of nitrates in the sampled wells. The concentration ranges for shallow wells was 1.1 to 357.7 mg-NO_3/l with a median of 18.5 mg/l (bucket), 4.4 to 229.8 mg-NO3/l with a median of 24.7 mg/l (pump) and boreholes ranged from 2.3 to 32.6 mg-NO_3/l with a median of 5.45 mg/l. The highest mean value determine was 65.48 mg-NO_3/l. These value was determined in shallow wells (maximum and mean values) were all above WHO recommended standards of 50.0 mg/l for drinking water (World Health Organization, 2008) and the boreholes were safe. These results indicated a low/negligible influence of water collection methods on the determined high nitrate concentration. High nitrate levels were determined from the wells located at Mji mpya and Babati wards. Most of the wells which had high nitrate levels above TBS and WHO standard limits were collected from these areas (Fig. 13). The wards are situated at the town center near the bus terminal, where the concentration of buildings was high compared to other locations. The increased settlement in the area is associated 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 in other areas/wards/streets. For surface water sources the maximum mean level was 7.74 mg/l which is far below the established national and WHO standards. The variation of nitrate levels determined may therefore be the attribute of various sources including the seeping nitrates composed wastes from nearby onsite septic tanks; nearby contaminated wells and other wastes released to the surrounding environment from domestics and during the application of nitrates composed fertilizers. High nitrate levels are also highlighted by Elisante and Muzuka (2017) as existing in other parts of the country. For nitrite (NO_2), the maximum concentration determined was 1.18 mg-NO_2/l which is below WHO recommended maximum of 3.0 mg-NO_2/l for drinking water. At present there is no nationally prescribed limit for nitrite concentration

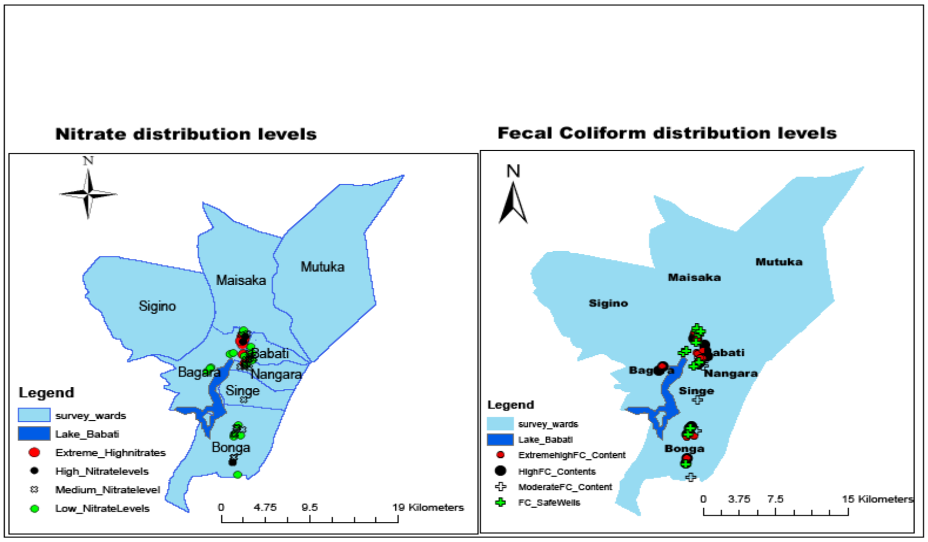
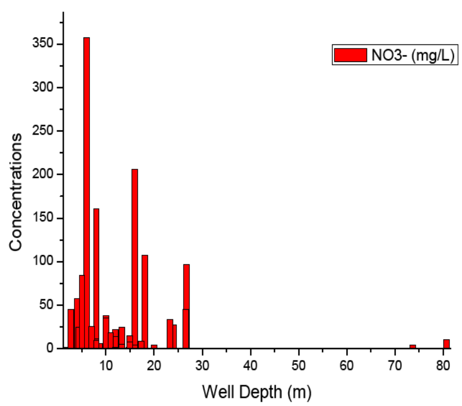


Figure 13: Pollution distribution (Nitrate and FC) levels in groundwater sources

Microbes: The microbial contamination results revealed the remarkably number of sources polluted with both Fecal and Total coliform bacteria. The results revealed further that the highest composition was detected in the shallow wells (Fig. 14) regardless of the water collection methods employed. The mean levels determined showed variations in compositions among well types versus water collection methods as a result from the deferred individual finishing/design of the sources, their location and the water collection methods used to obtain water from the sources. The use of manually operated rope and bucket system to collect water from the sources is considered unsafe because the water retuning back during the extraction may result into increased contaminations. Un-alignment of sources which was found existing to about 70% of all the sources is another remarkably potential pathway for the determined high contaminations levels and the varying concentrations among the sources. Unlined wells are more susceptible for contaminations because the leaching waste water can easily find its way into the sources to escalate the risk. Other emerging potential to cause the variations are including the near onsite sanitation facilities found being sited near the water sources and the polluting activities taken place near the source surrounding environments. In the boreholes the mean concentrations were 9.33C/100 ml and 0.0C/100 ml for TC and FC respectively. Only one source out of six boreholes tested indicated the presence of TC and the rest were all safe from both TC and FC bacteria. These results indicated that the contamination values were above WHO standards of 0C/100 ml for FC in the shallow wells with exception of boreholes which were considered safe from fecal coliforms contaminations. The Statistical analysis results showed that FC had a significant variation *($P<0.05$, $N = 43$)* for all the well groups tested with exceptions of the TC which shown none significant variations (*$P>0.05$, $N = 6$)* for boreholes. For surface water source both TC and FC showed significant variations among the sources and the mean values determined was up to 228.23 C/100 ml and 82.81C/100 ml for TC and FC respectively. The variations are deposited organic matter and other contaminants get into the sources along the path water flows. Coliform bacteria are found in the environment and in feces of human and animals. The presence of these pathogens is associated with waterborne diseases such as nausea, vomiting, fever and diarrhea diseases which may be caused by source contamination, and or failure of water treatment (Smith, 2001)



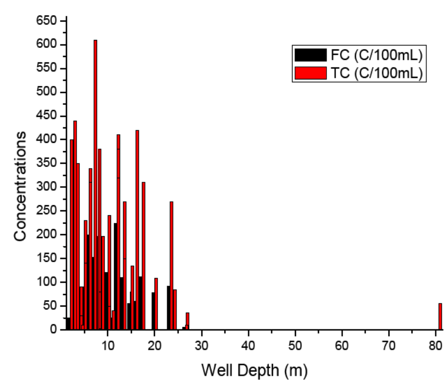


Figure 14: Correlation of Nitrate and microbial concentrations against well depth

Total phosphorus (TP) and phosphates (PO_4): The mean maximum concentrations results for total phosphorus (TP) in groundwater sources was 0.21 mg/l and the distribution values were none uniform among the wells. The statistical t-test results shown significance variation of TP among the sources. Phosphorus variations between hydrologic sites can be attributed to the natural mineral composition in the area and the application of phosphorus fertilizers on farms (Ulén and Snäll, 2007). Phosphorus fertilizer is inefficiently absorbed and during rainfall, it can be transported by flowing rain water to causing varying concentrations in nearby water sources in which the water enters. Phosphorus is an essential element for both plants and animal growth and a source formation of phosphates (PO_4) in water. The respective PO_4 maximum mean concentrations detected in surface and groundwater was 0.36 mg/l and 0.68 mg/l which are all within the WHO standard limits of 6.0 mg/l. The consumption of water containing high levels of phosphate is associated with digestive health problems (Kotoski, 1997; Domagalski, 2012).

COD: The minimum and maximum mean concentration recorded in groundwater were 7.40 mg/l- 19.88 mg/l and the statistical analysis results indicated a significance variation of the COD values of the tested wells implying a variation of chemical compositions in the groundwater of Babati depending on the location of the source. In surface water the mean value obtained was 9.12 mg/l. The mean values indicated were therefore exceeding WHO standard limits of 10.00 mg/l in the boreholes whereas the rest the wells and the surface water had a conformity with the established standards. Chemical oxygen demand is the amount of oxygen required to chemically oxidize organic matter. Chemical oxygen demand (COD) levels are an indicator of greater amount of oxidizable organic matter in water which reduces dissolved oxygen (DO) levels. Reduced dissolved oxygen may affect microbial decomposition to a level detrimental to aquatic life.

Fluorides: The fluoride mean contractions ranged from 1.09 mg/l – 1.28 mg/l and maximum mean value determined in surface water was 1.48 mg/l. These concentrations are within standards limits of 1.5 mg/l and 4.0 mg/l for World Health Organization and Tanzania Bureau of Standard (TBS) respectively. The statistical results showed significant variations ($P<0.05$) among sources which are being associated to the impact of the minerals composed in the bed rock in which the wells were positioned and surface water follow through. Fluoride in groundwater occurs naturally as an attribute of the geological composition, underlying water table. The consumption of high amount of fluoride can cause fluorosis diseases in children which has been reported as a death cases in some parts of the world (Rao *et al*., 2017)

4.5.4 Comparing water quality of surface water, deep wells and Shallow wells

The evaluation of the concentration value between deep wells, shallow wells and surface water sources (Fig. 15), revealed the highest nitrate mean levels in shallow wells as compared to other sources and high microbial compositions was found in shallow wells and surface water sources. The shallowest water table locations are shown by Fig. 16. Deep wells had the lowest concentrations of the most tested parameters as to compare with the other sources.

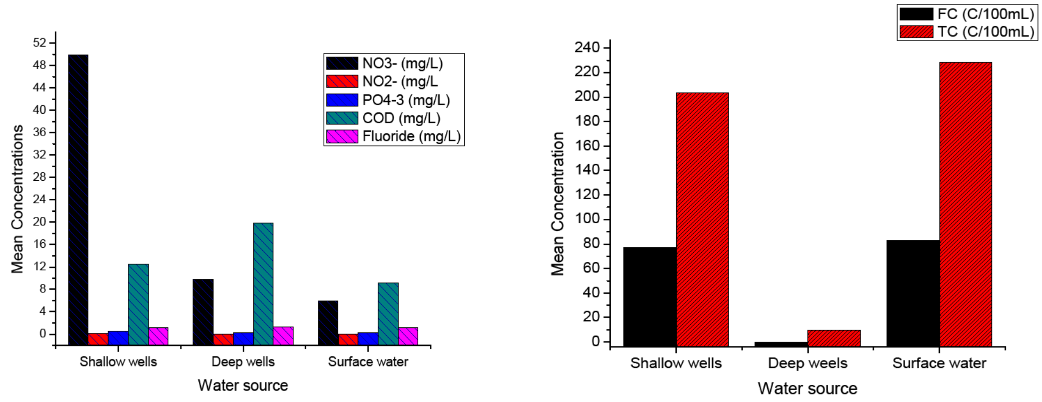


Figure 15: Correlation of NO_3, NO_2, PO_4, COD, F and microbial concentrations of surface water, deep wells and shallow wells

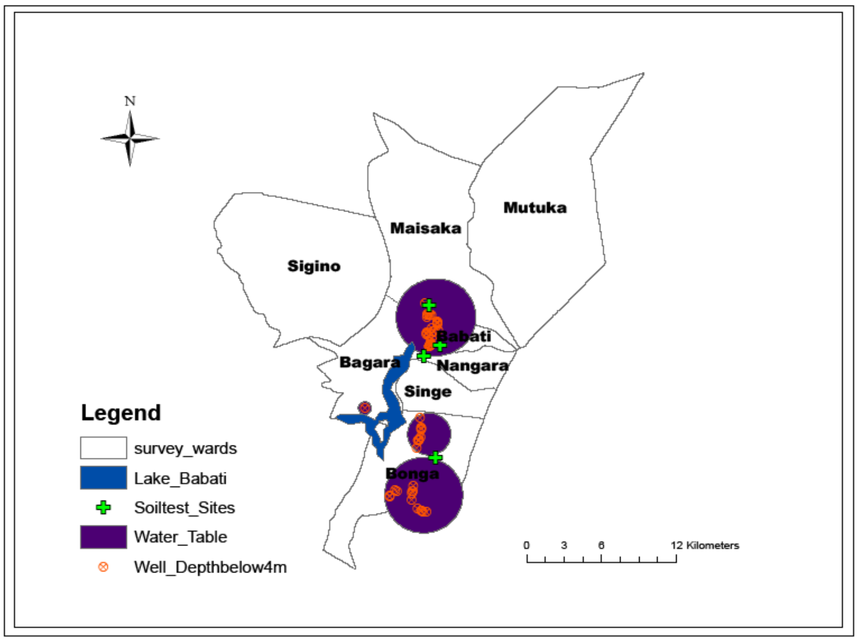


Figure 16: Shallowest well depth (<4 m) and soil sampled site locations

4.5.5 Groundwater risk index and vulnerability map

To accomplish the study a summary composed of 435 measured well points drill lithology of four BAWASA boreholes and laboratory soil test results were used to determine the information for parameter A and I . Other parameters such as D and C which were useful in the development of the final map could also be determined. The information for well depths were obtained onsite through direct measurements using piezometer. In the case that the parameter has shown to affect the vulnerability index, it becomes easy to interpolate and create the map. In this study to generate the groundwater contamination risk, the map of the DRASTIC parameters and pollution/hazard distribution map (Fig. 17) were juxtaposed over each other. The vulnerability results as per the DRASTIC equations $Vi = 5Dr + 4Rr + 3Ar + 2Sr + 1Tr + 5Ir + 3Cr$ (Refer Equation 2) indicated an overall indexes ranging from 80-99. These values were divided such that the vulnerability values less than 79 represented the low degree of vulnerability; others were the medium (80-99) high degree of vulnerability (100-200) and above 200 very high degree of vulnerability (Haouchine *et al.*, 2015). General aquifer of Babati town may be classified as moderately vulnerable to contaminations. The results maps indicate increased groundwater contamination risk in the areas with shallowest well depths. Maisaka ward showed very high risk in Kiongozi area (Fig. 17) and some parts of Babati and Mjimpya wards also shown the increasing trend. In the development the map the depth to water (D) and the soil media were the main controlling factor.

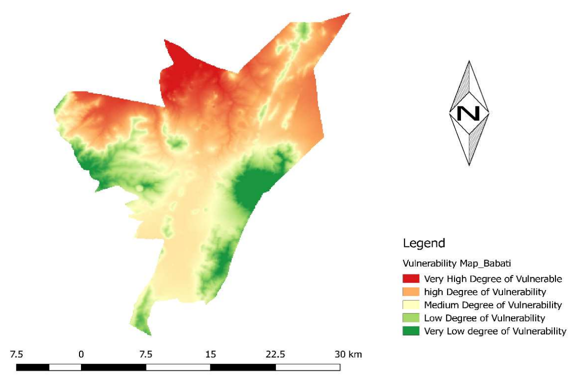


Figure 17: Babati town groundwater vulnerability map

CHAPTER FIVE

CONCLUSSION AND RECOMMENDATIONS

5.1 Conclusion

Groundwater is a major source of domestic water in large part 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. Although the practiced methods to draw water from these sources were considered safe for the sources, still the wells indicated presence of bacteria and nitrate level in a remarkably high concentration in the shallow wells as compared to the boreholes. Consumption of inadequately treated water from the local shared or individual sources may cause health problems. The groundwater vulnerability risk index revealed a moderate vulnerable contamination with increasing risk to some areas of Babati and Bagara wards found with shallowest well depths. This indicates that shallow wells are more susceptible for contaminations which are requiring the community to prudently avoid using the shallowest wells, which are the most at risk. Well water should also be boiled before consumption, while better and more sustainable solutions are sought to address the problem. It is anticipated that the findings of this study could be used as a baseline source of information for initiatives for solutions, to cover the knowledge gaps arising from current sanitary facility design and distribution problems, and existing regulations to minimize groundwater contaminations and the persistence of pollutant chemicals and resistance antibiotics through drinking water sources in developing countries like Tanzania.

5.2 Recommendations

(i) Further research/study on hydrochemistry of water for better management of groundwater resources and its quality.

(ii) A strategy to deliver education (knowledge based) to the stakeholders to ensure proper well constructions and appropriate water sources management in rivers and springs to minimize pollutions.

(iii) Education is needed for people who use and consume water from surface waters sources and private wells on daily basis to treat/disinfect water before drinking

(iv) The community should avoid the disposal of animal and human faecal into inadequate facilities near groundwater sources.

(v) Review of the existing regulations to accommodate un-encountered standards for water sources management and to ensure that are into enforcement

(vi) Installation of town sewer system and a designated waste water stabilization ponds to reduce onsite fecal sludge disposal and contaminations resulting from septic tanks

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APPENDICES

Appendix 1

QUESTIONNAIRE AND/ CHECKLIST FOR THE IDENTIFICATION OF SANITARY RISK ON THE ENVIRONMENT (SOIL AND GROUNDWATER)

General Information

Location (Town, ward, street)………………………….

GPS readings ………………………………………

Depth of the well…………………………Depth of Sanitary Facility………………...

Date of Inspection………………………..

Water Sample No………………………………

Name of Collector ……………………………

	A. Checklist questions for sanitary inspection of groundwater sources	**Risk**		**Remarks**
		Y	**N**	
1.	Is there a pit latrine near the well within 10m?			
2.	Is there any dumping yard for animal and or domestic wastes within 10m of the well			
3	Is there any pond of standing water around the concrete floor of the well			
4	Is there a surface water found within 10 m to the well			
5	Is there a pit latrine on higher ground than the well?			
6	Are there cracks on cement floor surrounding the well?			
7	Is the cover of the well in adequate cleanness			
8	Are there other latrines within 30m of the well?			
9	Are there any uncovered wells within 30 m of the wells/borehole			
10	Is the concrete floor les that 1m around the well			
11.	Is there inadequate fencing around which might permit animals in?			
	B. inspection for fecal sludge disposal practices and Environmental contamination			
12.	Do you have toilet?			

13	What type of toilet do you have in the household? 1. Pit latrine …….. Flashed toilet ……… No toilet …….. Others (specify)			
14	If you don`t have a toilet, where do you defecate? …………………………………………………………………			
15	How many of you/households share a single toilet?			
16	How do you dispose fecal sludge waste?			
17	Where do you dispose faecal sludge? Is there a disposal area?			
18	What is the means of conveyance/transport of fecal sludge to the disposal site			
19	Are there any open defecation areas around?			
20	How do you dispose other household waste? ………………………………………………………………………			

Appendix 2

Questionnaire for latrines found within 60 meter radius to water sources

General Information

Location (Town, Ward, Street)………………………………………………………..

Total number of latrines identified…………………………………

Batch number given …………………………………

Descriptions of latrines under this batch (*More than one form can be used for surveying other latrines identified*)

Latrine number ……………………..

- **Location (GPS) X –Coordinate………………….. Y-Coordinate………………… elevation………….. Depth …………………………….**

Inspector's Name & Date ……………………………

	B. Checklist questions	**Risk**		**Remarks**
		Y	**N**	
1.	Age of latrine …………………………………………			
2.	Latrine functionality ………………………………………………………………………			
3.	Number of people sharing the latrine ……………………………………………………….			
4	Distance of the latrine to water source ……………………………………………………….			
5	How often full ……………………………………..			
6	Construction materials used ……………………………………………….			
7	Condition of the area surrounding the latrine ……………………………………………………………			

RESEARCH OUTPUT

Journal Article:

Pantaleo, P. A., Komakech, H. C., Mtei, K. M. and Njau, K.N. 2018. Contamination of groundwater sources in emerging African towns: the case of Babati town, Tanzania, Water Practice and Technology. Vol 13 No 4, IWA publishing, doi: 10.2166/wpt.2018.104

Poster Presentation

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980
Water Practice & Technology Vol 13 No 4
doi: 10.2166/wpt.2018.104

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

Water Practice & Technology Vol 13 No 4
doi: 10.2166/wpt.2018.104

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.

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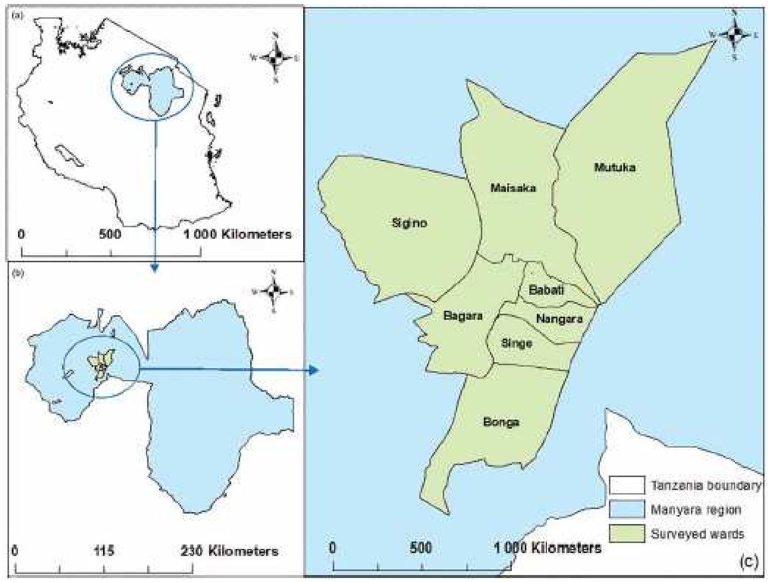

Figure 1 | Babati and the town wards.

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),

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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)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	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

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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.

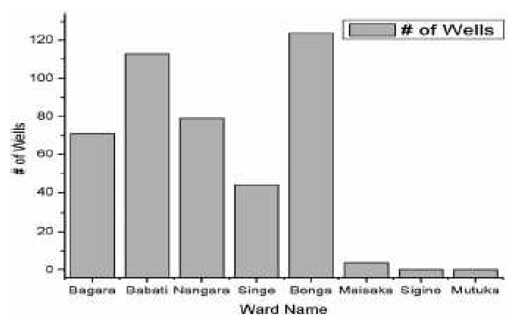

Figure 2 | Groundwater source distribution by ward.

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).

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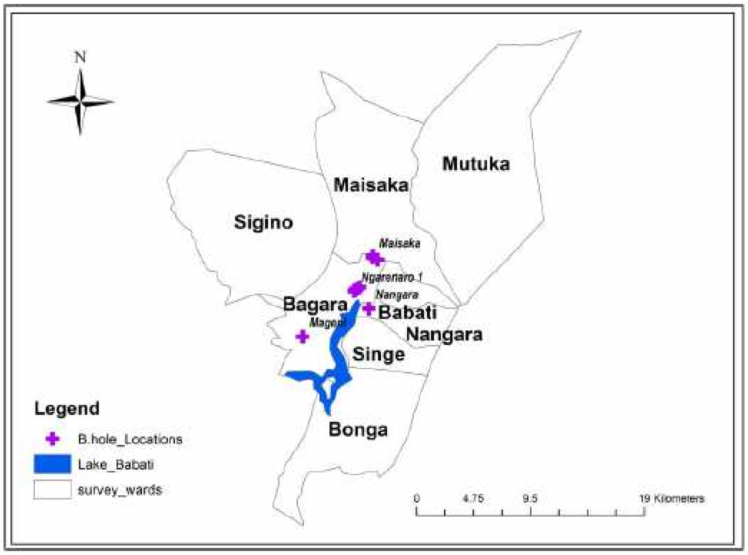

Figure 3 | BAWASA operated boreholes.

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.

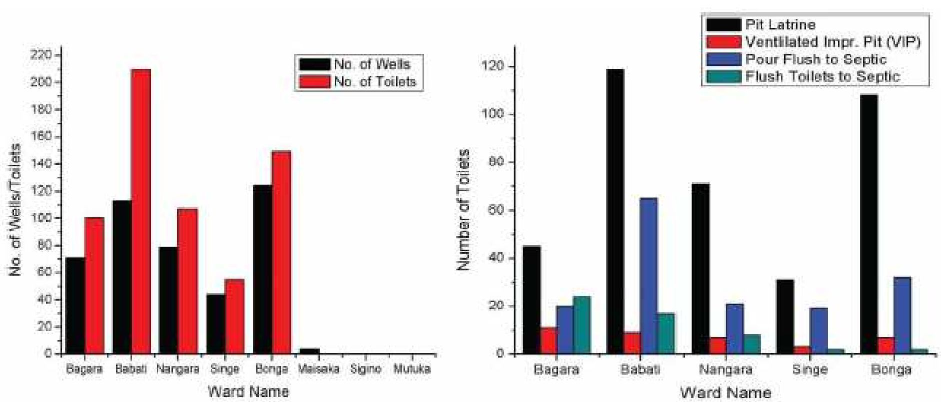

Figure 4 | Numbers of wells and sanitation facilities within 60 m of each other, by ward.

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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

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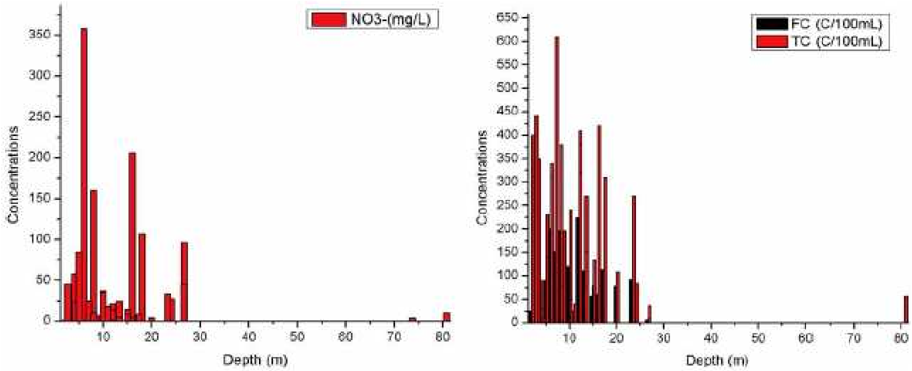

Figure 5 | Correlation of NO_3 and microbial concentrations with well depth.

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

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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

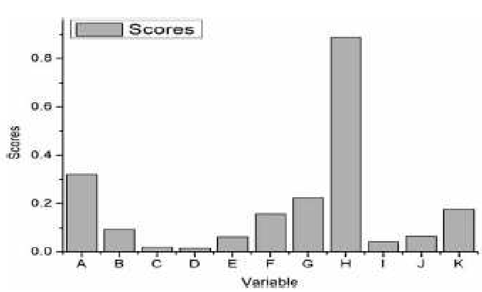

Figure 6 | Sanitary risk inspection results.

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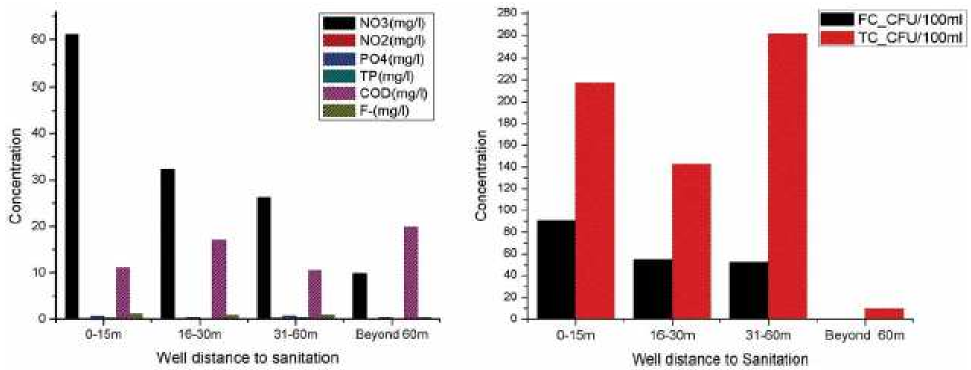

Figure 7 | Correlation of NO_3, NO_2, PO_4, TP, COD, F, and microbial concentrations against well distance from sanitation.

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.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Government of the United Republic of Tanzania through the Tanzania Atomic Energy Commission (TAEC) for funding this study. Other acknowledgements are due to Water Aid-UK and the Nelson Mandela African Institution of Science and Technology (NM-AIST) for their support in accomplishing the field and laboratory works.

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RISKS OF SANITATION FACILITIES TO GROUNDWATER POLLUTION IN BABATI TOWN, TANZANIA

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Introduction

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 uses. This is due to easy access and the high cost of piped water connections and monthly water charges by BAWASA. It is well known that consumption of water from impromptu sources with unknown quality results into eruption of waterborne related diseases (Elisante and Muzuka, 2016). The shallow wells are constructed on small plots with no account taken of potential adverse impacts may arise from nearby sanitation facilities and other pollution sources. Most sanitation facilities in the area are reported to be poorly constructed, and are likely to contaminate the land (URT and SNV, 2014).

This study was conducted to assess the risk arising from the interaction of sanitation practices and facilities with groundwater resources in the fast growing town of Babati in northern Tanzania.

Objectives

General Objective.

To assess the risks of sanitation facilities and develop pollution risk index arising from their interaction with soil and groundwater in Babati town

Specific objectives

- To identify and map current sanitation facilities and their associated environmental risks in Babati town
- To identify surface and groundwater pollution pathways in Babati town.
- To assess and map groundwater quality, soil and hydro-geological characteristics of Babati town
- To develop groundwater risk index and vulnerability map

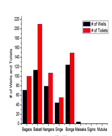
Significance of the Study

- Provision of potential for groundwater contamination in the urban setting of a small town
- Provision of information related to wells proximity to sanitation facilities, the management status of water sources and their potential influence
- Established pollution risk index and groundwater vulnerability map

Methodology

Cadmium reduction- NO_3 Diazzotization-NO_2	Membrane Filtration – FC and TC Ascorbic acid- PO_4	DRASTIC Method- Vulnerability index (VI)

Results



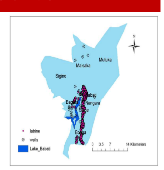


Figure 1: Number of wells and sanitation distribution at a radius of 60 m per ward

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.

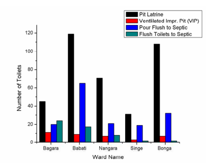


Figure 2: Sanitation types at 60m radius to groundwater sources per ward

Sanitary risk results showed that sanitation within 30 m of wells was the leading risk. 102 (23%) wells were within 10 m of sanitation

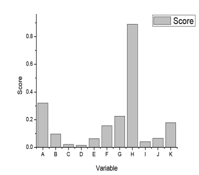
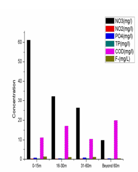


Figure 3: The sanitary risk inspection results.



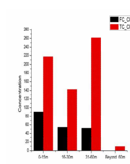
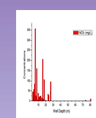


Figure 4: Correlation of NO_3, NO_2, PO_4, TP, COD, F, and microbial concentrations against well distance to sanitation



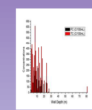


Figure 5: Correlation of Nitrate and microbial concentrations against well depth

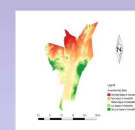


Figure 6: Babati town groundwater vulnerability map

Conclusions

- Results indicated presence of bacteria and nitrate level in a remarkably high concentration in the shallow wells as compared to the boreholes. Consumption from these sources may cause health problems if pretreatment not done
- Groundwater vulnerability index revealed a moderate vulnerable contamination with increasing risk to some areas of Babati and Bagara wards found with shallowest well depths
- The community should avoid using the shallowest wells, which are the most at risk and boiled water before consumption

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