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Research Article

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Assessment of Water Quality in Boreholes and Wells in Waa Location, Kwale County - Kenya

Kilwake J. Wanjala[1], Mwakio Tole[1], Musundi Sammy[2]*

[1]Department of Environmental Science, Pwani University, P.O. Box 195 - 80108, Kenya
[2]*Department of Physical Sciences, Chuka University, P.O Box 109-60400- Kenya

Abstract Water from boreholes and dug wells is extensively used in Kwale County, especially by rural communities living away from established market centers, where piped water is commonly available. The study aimed to assess the quality of water in boreholes and dug wells found in Waa location of Kwale County – Kenya. Selection of the boreholes and dug wells was carried out using purposive sampling and simple random sampling. All the seventy one boreholes and wells in Waa location were visited and inspected to determine their sanitary condition and functionality. Twenty eight samples of water that were collected in duplicate from 14 boreholes and dug wells (30% of total number) were analyzed for faecal coliform (*Escherichia. coli*), total coliform count, pH, total dissolved solids, turbidity, colour, total hardness, salinity, chloride content, electrical conductivity, total alkalinity, Ca^{2+} and Mg^{2+} using 3M Petrifilm™ method, pH meter, HACH digital titrator, Total dissolved solids/Conductivity meter, and DR 2000 (HACH) spectrophotometer at KIMAWASCO laboratory. The study revealed that 32% of the boreholes and dug wells have either permanently or temporarily failed to discharge good quality drinking water to the local community reliably. This state has been attributed to negligence from the relevant authorities and agencies in terms of water quality monitoring and low level of community involvement in the development of these water projects. The County government of Kwale and water resource providers should build the capacity of the community in water resource management, introduce desalination and water treatment plants to provide safe drinking piped water.

Keywords Boreholes and dug wells, water quality, purposive sampling and simple random sampling

ABBREVIATIONS AND ACRONYMS

AU:	African Union
BH:	Bore Hole
BTL:	Base Titanium Limited
DFID:	Department for International Development of the United Kingdom
EPA:	Environmental Protection Agency
ESRC:	Economic and Social Research Council
JKUAT:	Jomo Kenyatta University of Agriculture and Technology
KARI:	Kenya Agricultural Research Institute
KIMAWASCO**:**	Kilifi-Mariakani Water and Sewerage Company limited
KISCOL:	Kwale International Sugar Company Limited
KMD:	Kenya Metrological Department
KWAHO:	Kenya Water for Health Organization
KWSP:	Kwale Water and Sanitation Project
SCHPTP:	South Coast Hand Pumps Testing

KOICA:	Korea International Cooperation Agency
NERC:	Natural Environment Research Council of the United Kingdom
NGO:	Non-Governmental Organization
RFL:	Rural Focus Development
SIDA:	Swedish International Development Agency
SIWI:	Stockholm International Water Institute
UK:	United Kingdom
UN:	United Nations
UoN:	University of Nairobi
VIP:	Ventilated Improved Pitlatrine
WASREB:	Water Services Regulatory Board
WHO:	World Health Organization
WRMA:	Water Resources Management Authority
WSBs:	Water Services Boards
WSPs:	Water Service Providers.

Introduction

Water is crucial for human health and dignity, as a driver for business, for food and energy security and for the ecosystems upon which our societies and continued development depend [1]. It is one of the abundantly available substances in nature and has been regarded as being a vital necessity of life since it forms part of every living cell. At a basic level, everyone needs access to safe water in adequate quantities for drinking, cooking, personal hygiene, and sanitation facilities that do not compromise health or dignity [2]. Human activity and the prevailing climatic changes threaten groundwater resources.

Seawater intrusion on coastal water resources is of concern as there is predicted sea level rise resulting from global warming [3]. The impact of sea water intrusion at the Kenyan Coast was reported to be increased by the highly porous nature of the underlying coral limestone formation, and reduced rates of groundwater recharge as urban centers and roads are paved [4].

In the study area there is lack of springs, water sheds, dams, rivers or lakes. Hence the groundwater is the main source of domestic water supply [3]. There have been uncertainties on the availability and quality of water due to the fact that boreholes and dug wells have adequate water during rainy season but they dry out or have a lower water level than expected during dry season [5].

The scarcity of water is an old problem in the area and as a consequence, a number of boreholes have been dug, but there is scanty information on their registration at WRMA Mombasa. Bureaucratic procedures that are unfriendly to the borehole developers have greatly contributed to registry problems. The authorities accepted this condition as there are insufficient boreholes; hence no drilling profiles of the boreholes are registered although this is mandatory by law [5].

There is a correlation between the quality of some of the groundwater sources developed in Kwale County, particularly between pit latrine waste and the groundwater system, with respect to the differing geological conditions [3]. Many hand pumps are non-functional and cannot be fixed due to other available water resources, lack of active water committees, unavailability of spare parts and insufficient funds [6].

This study set out to assess the number of functional wells and boreholes in Waa location of Kwale County, and also determine the quality of water in the selected functioning wells and boreholes.

Clean, quality, drinking water is remarkably inadequate in Kwale County. Given the scarcity of the natural surface freshwater sources in the County, efforts have been directedat the construction of earth dams, digging wells and maintenance of a few available perennial springs [5]. Boreholes and dug wells are used extensively by rural communities in the County for the supply of water from the ground as they have provided a considerable part of the community demand both for drinking water and for the other purposes like sanitation and agriculture [5]. The boreholes and dug wells have been suitable in places where the groundwater is not very deep for easy extraction [5]. The unreliable water supply in Kwale County by the state owned water companies (i.e. Kwale Water and Sewerage Company limited and WRMA), has forced private individuals and other partners to drill boreholes and hand dug wells for private and commercial purposes [4].

The critical stakeholders for developing water systems in Kwale County are; Water Resource Management Authority (WRMA), Tenda Pamoja (NGO), Team and Team International, Korea International Corporation Agency (KOICA), PLAN International, Red Cross, Samaritan's Purse, Biosand Water Filters, WASREB and the local communities. For instance, Tenda Pamoja, a Dutch foundation together with other international foundations such as the Swedish International Development Cooperation Agency (SIDA) and Kenya Water for Health Organization (KWAHO) have invested in the water system of Kwale County for some time. The SIDA project concentrated on protection of springs, water harvesting systems, dam construction and borehole drilling between 1977 and 1989 [5]. The project drilled 577 boreholes mainly in the coastal strip due to unavailability of water, but out of the 577 boreholes, only 230 are still working although only 60 (10.40%)are in good working condition [5]. The SIDA project was named "KWALE DISTRICT WATER SUPPLY AND SANITATION PROJECT".

The Kwale Water and Sanitation Project (KWSP) was started in 1985 as an extension of the South Coast Hand Pumps Testing Programme (SCHPTP), with the aim of drilling boreholes and installing hand pumps which would be operated by the recipient communities. These pumps would also help in protecting perennial springs. Other aims were to provide assistance to self-help groups on piped water supply schemes; constructing ventilated improved pit (VIP) latrines and conducting health education campaigns [4].

Other minor actors in the water sector in Kwale County include; the Ministry of Planning and National Development, the Ministry of Environment and Natural Resources, schools, the Children Department and the Social Services Department of the Ministry of Home Affairs [5]. These stakeholders have a common interest in the proper management of water resources in the County although they are not visible on the ground. Otherwise, they have the state authority, investment capabilities, technical knowledge as well as the will and power to keep the system functioning well for a long period if they decide to execute their mandate effectively.

Funding institutions and partners in groundwater research program in Kwale County are Natural Environment Research Council (NERC) of the UK, the UK Economic and Social Research Council (ESRC), Department for International Development (DFID) of the UK, Oxford University, Base Titanium Limited (BTL), Kwale International Sugar Company Limited (KISCOL), Jomo Kenyatta University of Agriculture and Technology (JKUAT), University of Nairobi (UON), Rural Focus Limited (RFL), Kenya Agricultural Research Institute (KARI), Kenya Meteorological Department (KMD) and Kwale County (Mutua et al., 2014).

The major groundwater users in the County include the thriving tourism industry (Hotels), Kenya's largest mine (Kwale Mineral Sands Project) undertaken by Base Titanium company with a peak groundwater abstraction of 5400m^3 per day, the Kwale County which serves a large portion of Kwale County and thousands of hand pump users [6]. According to Mutua, 2014, a research titled "Groundwater risks and institutional responses in Kwale County, Kenya in 2013", large scale commercial agriculture being undertaken by Kwale International Sugar Company Limited (KISCOL) is among the topmost groundwater users in the county. The projection given by KISCOL is 5,000ha of sugarcane to be irrigated in the County at an average demand of 70,000 m^3 per day from the projected 26 - 52 boreholes [6].

Alternative drinking water sources in Kwale County comprise of public taps, wells, boreholes, unprotected springs, rain water, tank track, cart/bicycle with jerricans and surface water among others. A complete register of the boreholes does not exist but according to Kwale water point mapping preliminary results 2014, a research done by Mutua *et al.*, 2014, Kwale County has a considerable number of functioning and nonfunctioning boreholes as shown on the map, Figure 1 [6].

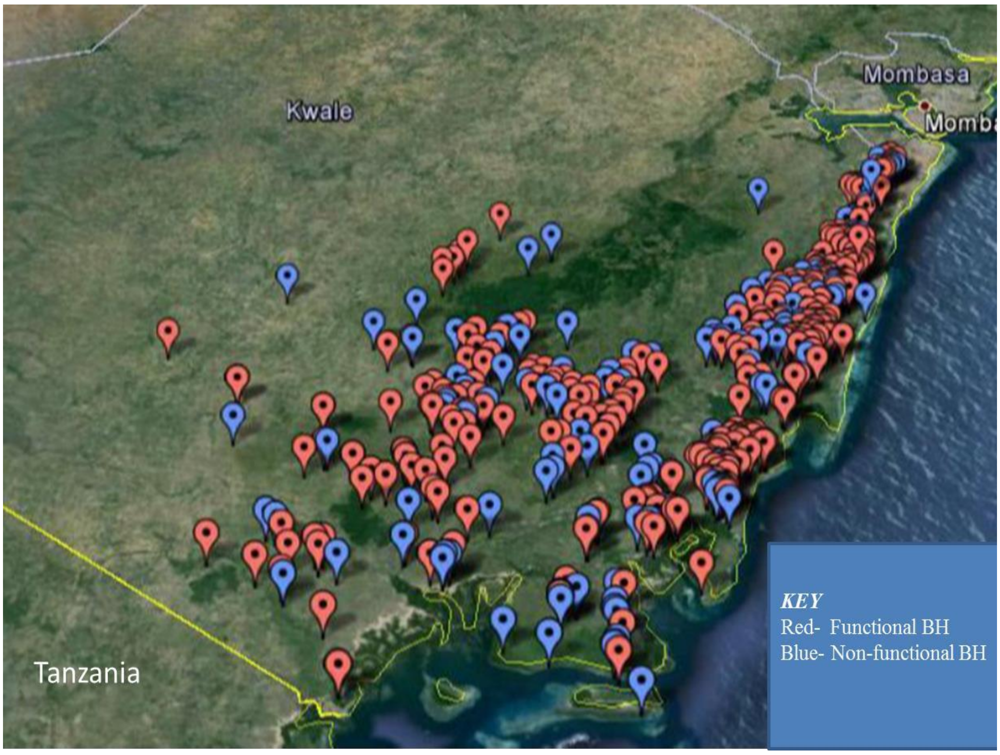

Figure 1: Distribution of Afridevs (water points) by functionality status in Kwale County.
Source: Kwale water point mapping preliminary results, sept 2013 (research sponsored by ESRC & DFID)

Methodology

Research Design

The data for this study was obtained from two different sources that is, primary and secondary sources. The primary sources of data used include the following.

1) Survey study: A reconnaissance survey was undertaken by the researcher to determine the number and actual locations of the various boreholes and dug wells in Waa location through the use of hand held GPS. A survey was conducted to ascertain the sanitary conditions and status (working or not working) of all the boreholes and dug wells found in the study area.

2) Oral interview: The local administration, village chairmen/women and members of the community were orally interviewed on how they fetch water and perceptions of boreholes and wells. This was to establish the locations of water point names, status and the management measures inplace.

3) Experimental design. The samples collected were analyzed in the laboratory to establish the level of contamination by each parameter. The results were used to determine the compliance of different samples with WHO guidelines and EPA standards.

4) Secondary data sources. Secondary data relevant in the study such as WHO guidelines and EPA standards for drinking water were collected through journals, textbooks, magazines, gazettes and internet materials.

5). Sampling technique. A six-man research team was constituted with the researcher as the head of the team: one degree holder in water related issues, one advanced level certificate holder working in the laboratory, two senior primary school certificate holder and two locals who doubled up as our drivers using their motorbikes throughout the study period. The research assistants had two days training to enable them assist in introducing, explaining study objective to the concerned communities and inspecting wells to assess their sanitary conditions.

A purposive and simple random sampling techniques were used to select water points to be sampled as there were 48 operational boreholes and dug wells in the study area out of 71 initially identified. Purposive random sampling was used as it provided a better opportunity for the researcher to ensure that key concerns pertaining to sanitation and contamination in boreholes and dug wells from the study area are addressed. Simple random sampling was used to minimize the biasness in borehole and dug well selection, as it gave fairly equal chance for each water point to be sampled.

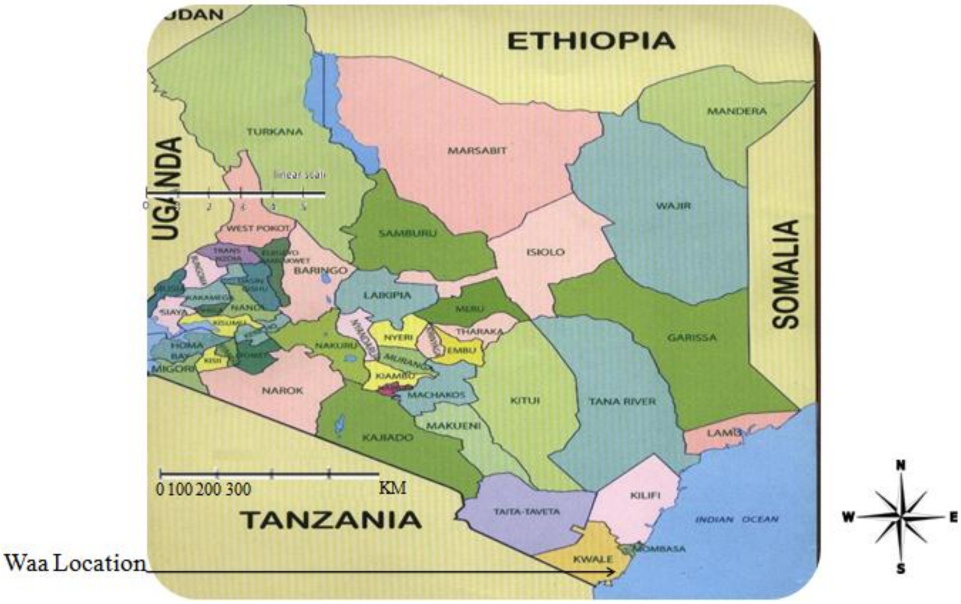

Figure 2: Map of Kenya showing the project area - Waa location
Source: Google maps

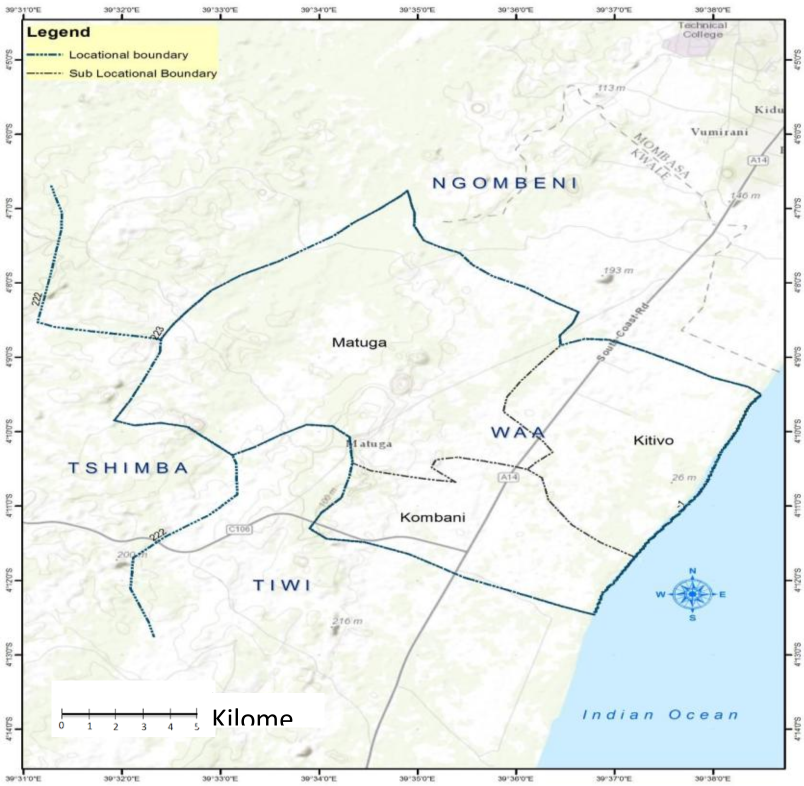

Figure 3: Map showing location boundaries of the study area
(Source: Authors construct (2016): Admin layers from IEBC, topolayers from ESRI's Arcgis service online)

Description of the Project Area and scope of study

This research was carried out in Waa location between Magandia Kwale eye clinic center and Map River, before Tiwi market. The area is located in Kwale County, Coastal zone of Kenya as shown below in figure 2. The study area is approximately bounded by longitudes +39°22'E and +39°36'E and latitudes -4°9'S and -4°30'S. The characteristic vegetation of the area is that of trees and natural grass, and the area is yet to be fully developed.

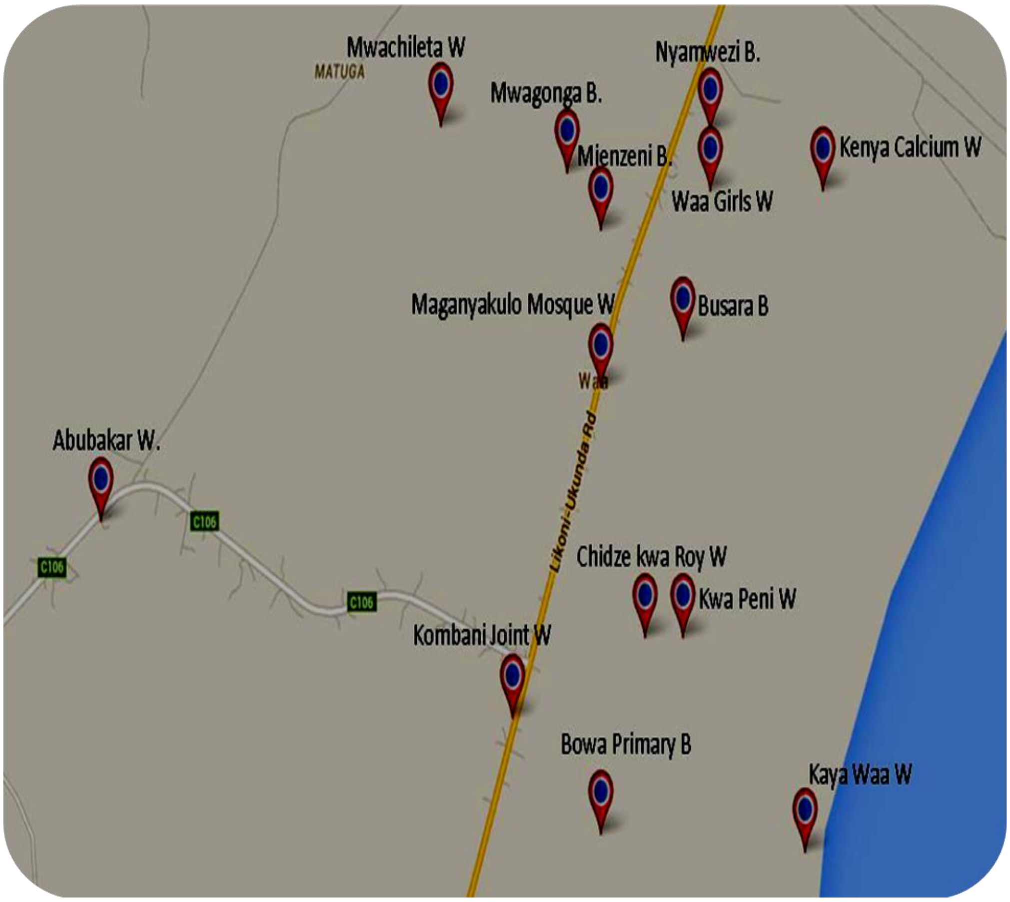

Figure 4: Map showing distribution of selected sampled boreholes in the study area

Waa location has been further subdivided to three sub locations namely;-

1) **<u>Kitivo sublocation.</u>**

The sub location comprise of the following **9** villages.

Key: - Cancellation (e.g. ~~Nyamwezi~~) signify Nonfunctional Borehole/Well

- Kitivo village. **Wells** -Waa girls, Kenya calcium, Waa primary, ~~Nyamwezi, ~~Waa stage mosque, Mwarapayo, Chiembedodo,~~ MaendeleoMvumoni~~, Osiepe/Mkunazinipetrol station. **B/holes**- Kadhangani/Nyanya, Nyamwezi, Maendeleo Mvumoni).
- <u>Mwagonga village</u> **(wells**-*0*,***B/holes***-*Waa boys, Ganzoni,Kumbo/Mwagonga, ~~Gogolo~~)*
- <u>Mwamshipi village</u> **(wells**-*Gulandze,* ***B/holes***-*Gulandze, KwaMwakibwende/mwakweli, Mwamshipi/swazuri, and Wakati*).
- <u>Maganyakulo village</u> (**wells**- *Maganyakulo mosque, Kitauro,* ***B/holes***-*0)*
- <u>Gwirani village</u> **(wells-** *0,* ***B/holes***- *Gwirani mosque,~~Magundo/Mwanondo~~)*
- <u>Mkokoni village</u> (**wells-** *kwaChiguruguru, Mwaruwa***,** *Mungai, Mutio,~~fatumagirigi~~, Munge mosque, Peni, White***, *B/holes***-*Busara/Mwadzowa, ~~Vibambani)~~*

- Kathangani village **(wells-** *Kadhangani, ~~Ngapa~~, Chidzekwa Ismael Zecha,***B/holes-** 0)
- Kaya Waa village **(wells-** *~~Gami~~*, Kaya *Waa mosque, Kaya Waacomm., Kaya Waa beach,* ***B/hole*** *– ~~Kaya Waa comm.~~*
- Bowa village **(wells-** *Gafa, Mbeto, MadarassaQadiriya, HaliMwinyi,Roy, Gakurya, MzeeHamisi,* ***B/holes****- Mshindo/Kidze*

Institutions i.e. schools and dispensaries (**11** in number) found in this sub location are;-

- Waa boys' secondary school.
- Waa girls' secondary school.
- Waa primary school.
- Mkokoni primary school.
- Kenya calcium primary school.
- Swafa primary junior academy (1 –6).
- Irishad integrated primary school (1 –7).
- Bridge international primary school (1 –7).
- Hamjan integrated school –Maganyakulo.
- Taw heed Islamic center – Maganyakulo mosque complex.

2) Kombani sublocation.

The sub location comprise of the following **5** villages.

- Matopeni village (**wells-** *Kombani joint bar,* ***B/holes-*** *Bowa primary, Bowa mosque)*
- Majengomapya village (**wells-** *Kwa Meja,* ***B/holes-*** *~~TiwibhMafimbo~~, Tiwibh Gasembi,*
- Chidzumu village (**wells- 0,** ***B/holes-*** *Tiwibh Mapu River~~, Kidzumumosque~~)*
- Chigongoni village **(wells-** *0,* ***B/holes-*** *, ~~Kitsanze~~, ~~Mwawasaa~~)*
- Mtsangatifu village **(wells-** *Tiwibh emirates,* ***B/holes****-0)*

The presence of the following institutions (schools and dispensaries) served as physical guides in accessing the study area;

- Kombani secondary school.
- Kombani primary school.
- Bowa primary school.
- Gagale primary academy
- Mama Amina primary academy.

3) Matuga sublocation.

This is the largest sub location of the three, and it comprise of the following **11** villages;

- Mbweka **(wells-** *Mwachileta***, *B/holes-*** *~~old Mbweka~~, ~~New Mbweka~~, ~~Mwaivu, Magombani)~~*
- Tumbula **(wells-** *0***,** ***B/holes****-0)*
- Makondeni **(wells-** *0,* ***B/holes****-0)*
- Kigato **(wells-** *0***,** ***B/holes****-0)*
- Voroni **(wells-** *Abubakar ,* ***B/holes****-~~Mng`ongoni/Bethany~~***)**
- Tsunguni **(wells-** *0***,** ***B/holes****-0)*
- Mwauchi **(wells-** *0***,** ***B/holes****-0)*

- Ganze **(wells-** *0*, ***B/holes****-0)*
- Mwatate **(wells-** *0*, ***B/holes-0)***
- Mienzeni **(wells-** *Magundo/Mwakuwania*, ***B/holes****-Mienzeni/Yeje)*
- Mabatani **(wells-** *0*, ***B/holes****-0)*

Institutions: schools and dispensaries (**13** in number) found in this sub location are;-

- Matuga girls' secondary school.
- Matuga primary school.
- Voroni primary school.
- Yeje primary school.
- Mbweka primary school.
- Ganze primary school.
- Matuga polytechnic.
- Vision of hope primary academy.
- Bethany primary academy.
- Abubakar primary school.
- Tumbula nursery school.
- Kenya school of government

Sample Size

During the study, a total of 71 boreholes and dug wells in Waa location were identified. The total target number of water points in the entire study area was made up of 48 working water points (21 boreholes and 27 hand dug wells) distributed across the three sub locations. A Sample size of 14 water points (5 boreholes and 9 hand dug wells) which constituted 30% of the total number of boreholes and hand dug wells in Kombani, Kitivo and Matuga sub locations were selected for the study. This sample was proportionally distributed to each of the three sub locations using the formula below [7].

$$P = \frac{n}{N} \times i$$

Where;-

-P represents the sample size picked upon.

- n represents the total number of boreholes and hand dug wells in each sublocation.

- i represent 30% of the total number of boreholes and hand dug wells in the entire Waa location.

-N represents the total number of operational boreholes and hand dug wells in the entire Waalocation.

- **Kombani Sub location**

$$P = \frac{07}{48} \times 14 = \mathbf{02} boreholesandwells$$

- **Kitivo sub location**

$$P = \frac{38}{48} \times 14 = 11\ boreholesandwells$$

09 were sampled instead of **11** due to their close proximity

- **Matuga sub location**

$$P = \frac{04}{48} \times 14 = 01\ boreholesandwells$$

03 were sampled instead of **01** as the area is so wide and with differing geology.

The sample size was therefore 14 (5 boreholes and 9 hand dug wells) from the three sub locations constituting Waa location.

Materials and instruments for Data Collection and laboratory testing

The data collection and analysis materials and instruments used in the study included the sterile glass bottles, cool box, alcohol, cotton wool, polyethylene bottles pH meter, HACH digital titrator, Total dissolved solids/Conductivity meter, and DR 2000 (HACH) spectrophotometer and apparatus in KIMAWASCO water, and sanitary engineering water laboratory found in Pwani University.

Sterilized glass bottles used for water bacteriological sampling (at least 200 ml capacity) were fitted with screw caps. The cap and neck of the bottle had been protected from contamination by a suitable cover either of thin aluminum foil while within the screw, were Silicon rubber liners.

Data Collection procedures and laboratory testing/analysis

Prior to the commencement of data collection, the researcher obtained all the necessary documents, including an introduction letter from the University. Audience with the sampled local authorities in the region was also sought to clarify the purpose of the study. Upon getting clearance, the researcher in person sought the assistance from the local authorities and community so as to have access to the boreholes and dug wells that were available in the study area. The procedures for data collection were as follows.

Faecal coliform and Total coliform

Total Coliform (TC)

The presence of any member of Total Coliform bacteria may indicate that the water supply is contaminated while its absence is usually interpreted as evidence of safe drinking water which has a low risk of waterborne infectious disease. The test for total Coliforms determines the presence or absence of these bacteria in 100 milliliters of sample.

***Escherichia coli* (EC)**

E. coli is a specific indicator for the presence of fecal contamination and its presence in water indicates the presence of material of fecal origin and thus a potentially dangerous situation, the nature of which should be determined by immediate investigation.

By determining this, we can determine whether or not the water supply, from which the sample was collected, is safe to drink.

For bacteriological analysis of borehole and dug well water, samples were collected aseptically in 200 ml heat-sterilized bottles containing a sufficient volume of sodium thiosulphate that was meant to neutralize the bactericidal effect of any chlorine in the water. Leaky taps were neglected since water flowing over the surface of the tap would have contaminated the samples. Just before collection of the sample, each container was rinsed three times with the water about to be sampled. The outside and inside of the tap nozzle was thoroughly cleaned with alcohol moistened cotton wool, after which the outside was flushed for one minute to remove any possible stagnant water from the line and to assure that a representative sample was obtained. Borehole water samples were allowed to flow freely for at least 5 minutes while the pumps were in operation to remove all the water contained in the casing, then fresh water samples from the aquifer was run into the bottles. Sample bottles were immediately stoppered, labeled using a water-proof marker with full details, and quickly delivered in cool box to KIMAWASCO laboratory within 12 hours. Cool box ensured protection of samples from light and any other changes that could have occurred in the bacterial content of water on storage. Laboratory examination of the samples were done within 24 hours of sampling. Total coliform and *E.coli* were assessed in all water samples collected from boreholes and dug wells. Total coliform is a standard indicator organism used to show general bacterial contamination in water. *E. coli* is also used to test drinking water, it points more directly to fecal contamination.

Petrifilm™ Testing

There are several standard methods such as membrane filtration, MPN, or chromogenic media methods that are used to test for total coliform and *E. coli* [8]. For this study, 3 M Petrifilm™ methods was used as it was simple, cheap, not requiring additional equipment and ease of transport [9].

A 1 milliliter sample of water was placed on the count plate culture medium and left to incubate at 35 °C for 24 hours in KIMAWASCO laboratory, Kilifi, after which the film was read by direct count. Any total coliform or *E. coli* colony forming units (CFUs) that appeared as red or blue dots were and recorded as per sample.

Physico-chemical Parameters

The borehole and dug well water samples were collected aseptically in one litre polyethylene bottles. The polyethylene bottles were prewashed with a detergent, diluted nitric acid and deionized water respectively. Just before collection of the sample, each container was rinsed three times with the water about to be sampled. The outside and inside too of the pump nozzle was thoroughly cleaned with cotton wool soaked in alcohol then flushed for one minute. Eventually pumping was stopped and using an alcohol burner, the outlet was flamed with sufficient heat for at least one minute and allowed to cool pumping once more to give a moderate flow before aseptically filling the polyethylene bottles. Well water samples were also collected using the bottles by tying a rope below their necks and 500 g stone under it. The cover of the bottles were aseptically removed, bottle lowered into wells to the depth of about 1 meter beneath the water and raised out of the well. Finally, their covers were carefully replaced, bottles labeled with full details, put into a cool box containing ice packs and transported immediately to the laboratory for analysis. Sample labeling was done as illustrated in Table 1 below with details of sample locations, sources and sample identification code on the same day.

Table 1: Sample locations, sources and sample identification code

No.	Sample Location	Source of Supply	Sample Identification Code
1.	Kitivo (Waa Girls secondary)	Well	**K1** (N & S)
2.	Kitivo (Nyamwezi).	Borehole	**K2** (N & S)
3.	Kitivo (Kenya calcium)	Well	**K3** (N & S)
4.	Mkokoni (Busara)	Borehole	**K4** (N & S)
5.	Mkokoni (Kwa Peni)	Well	**K5** (N & S)
6.	Kaya Waa (Beach)	Well	**K6** (N & S)
7.	Bowa (Kwa Roy)	Well	**K7** (N & S)
8.	Mwagonga (Kumbo)	Borehole	**K8** (N & S)
9.	Maganyakulo (Maganya mosq)	Well	**K9** (N & S)
10.	Voroni (Abubakar pry)	Well	**M1** (N & S)
11.	Mbweka (Mwachileta)	Well	**M2** (N & S)
12.	Mienzeni (Mienzeni/Yeje)	Borehole	**M3** (N & S)
13.	Matopeni (Bowa primary)	Borehole	**KO1** (N & S)
14.	Matopeni (Joint Bar)	Well	**KO2** (N & S)

KEY:

K- represents- samples collected from Kitivo sub location

KO- represents- samples collected from Kombani sub location

M- represents samples collected from Matuga sub location

N– Normal sample collected for physicochemical tests

S– Sterile sample collected for biological analysis

Water pH

A digital pH meter was used to obtain the pH of the collected water samples. Standardization of the instrument was done using buffer solutions: starting with acidic, neutral and lastly alkaline before the sample was poured into a test tube. Finally, the test tube containing each sample at a time was put into a pH meter and values read and recorded immediately. PH was assessed because it is one of the basic parameters for evaluation of the water quality and usually it can indicate the biological availability of chemical constituents such as nutrients and heavy metals.

Acceptable range for drinking purposes is from 6.5 to 8.5. Levels below 6.5 may be corrosive, while levels above 8.5 may create scaling problems and a bitter taste.

Turbidity

Testing for turbidity in water samples is significant because it provides a good picture of the amount of solids present. Solids can be a good vector for bacteria to enter a water source, and the more the solids present, the more disinfectant required to treat a given amount of water.

Turbidity was measured using DR 2000(HACH) spectrophotometer. For determination of turbidity in water samples, freshly prepared distilled water was filled into 25ml sample cell and another containing sampled water to be analyzed. The DR 2000(HACH) spectrometer instrument was used where its knob was turned to a programmed number of turbidity which was 750 and wavelength 450nm.The distilled water was inserted first into the cell holder and the lid closed, then the knob for zero was pressed to standardize the instrument. After that, the sample was inserted into the cell holder and the "Read" button pressed and the result was displayed on the display screen where it was noted and recorded.

Total Dissolved Solids (TDS)

In determination of TDS, 200 ml of distilled water and 200 ml of water sample were poured into two separate beakers. The TDS / Conductivity meter was switched on, and its sensor rod dipped into the beaker containing distilled water which gave a Reading of 0.00 mg/litre TDS. Later on, the sensor rod was dipped into the second beaker containing the water sample, where the TDS / Conductivity values were then displayed in mg/litre. The total dissolved solids is an indicator of potential concerns and further investigation has to be conducted. Often, high levels of TDS are caused by the presence of Nitrates or pesticides.

Chloride

In determination of chloride content in water samples, the following materials were used; Spectrophotometer DR 2000 (HACH), freshly prepared distilled water, mercury thiocyanate and freshly prepared iron (II) sulphate solution. A sample cell was filled with 25ml of freshly prepared distilled water and the second cell with sample water. The spectrophotometer was set at a programme number 70 and dialed to wavelength 455 then 2ml of mercury thiocyanate was added into each sample cell and swirled to mix. In addition, 1ml of iron (II) sulphate solution was pipetted into each sample and swirled to mix and let to stand for 2 minutes reaction time. Then the first solution (distilled water) was inserted first into the cell holder and lid closed, then the knob for the instrument was pressed to give 0.00mg/litre reading. Later on, the second solution was inserted into the cell holder and the "Read" button pressed to give chloride value in mg/litre that was then recorded.

Water Colour

The DR 2000 (HACH) Spectrophotometer was also used to determine the colour of the water samples using the same procedure as in turbidity measurement, only that the instrument was programmed at number 120 and wavelength 450nm. The units in Hazen of colour were observed and recorded.

Electrical Conductivity

It is a measure of the ability of the water to conduct an electric current. It is related to the amount of dissolved substances or ions in water but does not give an indication of which minerals are present. In most cases conductivity is about twice the total hardness in uncontaminated water, changes in electrical conductivity may indicate changes in the overall water quality, hence this is the overall test for water quality. If electrical conductivity is much greater than two times the hardness, it may indicate the presence of other ions such as Cl^-, NO_3^-, SO_4^{-2} which may be either human influenced or naturally occurring.

Total Hardness

It is of the amount of Ca^{2+} and Mg^{2+} ion in the water sample. It is primarily caused by water slowly dissolving rocks that contain calcium and magnesium. The most desirable range of hardness is between 80 and 100 mg/L as less than 80 mg/L may result in corrosive water. Hardness values exceeding 500 mg/L are generally unsuitable for domestic purposes without treatment. No health concerns are associated with drinking hard water but more often it appear undesirable as it builds up (scaling) in pipes and water heaters.

Hard water also wastes soap as it reduces the ability of the cleansing agent by reacting with it first before forming lather. Hard water also forms scum and causes graying on white pieces of fabrics over a long period of time, while in some cases hard water causes dry skin when people uses it frequently for showering.

Ca^{2+} and Mg^{2+} ions are essential nutrients in the bodies of living organisms. However, drinking hard water directly cannot be a significant source of dietary needs.

The recommended limit for Calcium is 75 mg/L [10], as when it is in excess, it may contribute to the formation of kidney or bladder stones.

The recommended limit for magnesium is 50 mg/Las excessive magnesium may give water a bitter taste, but is normally not a health hazard.

Water Salinity

Salinity in sea water is as a result of a complex solution made up of many things including mineral salts and decayed biological matter from marine organisms. Most of the ocean's salts are derived from gradual processes, such as weathering and erosion of the earths' crust and mountains by the dissolving action of rains and streams. Salts become concentrated in the sea because the Sun's heat evaporates almost pure water from the surface of the ocean, leaving the salts behind. These cations and anions dissolved in sea water, gives it a "salty" taste at levels greater than 180 mg/l. Salinity can have adverse effect on irrigation, soil structure, water quality and infrastructure. Salinity was measured as total dissolved salts that the sample contained.

Main Results and Discussion

The summary of the number of boreholes and hand dug wells found in the project area is as shown in the table 2.

Table 2: Summary of number of boreholes and wells in the project area

	All	**Working**	**Failed**
Total number of boreholes present	33	21	12
Total number of hand dug wells present	38	27	11
Grand total (boreholes + hand dug wells)	**71**	**48**	**23**

Note: Well and borehole functionality status.

Table 2 above shows that 28.95% of wells and 36.36% of the boreholes are not functioning. Higher percentage of boreholes have failed in the study area as compared to wells due to technical and financial implications involved in Afridevs management. Commissioning and operating a well require less funds and little technological knowhow as compared to the construction of a borehole, installation of pumps and management among other expenses. Distribution of boreholes and hand dug wells across the 3 sub locations in the project area is as shown in Table 3.

Table 3: Distribution of boreholes and wells across the project area

Sub location	**Total no. of wells and B/holes**	**Working**	**Failed**	**Sampled**
KITIVO	52 *(Wells=33, B/holes =19)*	37 *(Wells = 22, B/holes = 16)*	15 *(Wells=11, B/holes =04)*	09 *(Wells=06, B/holes =03)*
MATUGA	08 *(Wells = 03, B/holes = 05)*	04 *(Wells=03, B/holes=01)*	04 *(Wells = 00, B/holes = 04)*	03 *(Wells=02, B/holes =01)*
KOMBANI	*11 (Wells = 02, B/holes = 09)*	07 *(Wells=02, B/holes =05)*	04 *(Wells = 00, B/holes = 04)*	02 *(Wells=01, B/holes =01)*

1) KITIVO sub location has got the highest number of boreholes and dug wells (74.65%) in Waa location as compared to the other two sub locations. The high number of these water points has been attributed to several factors such as:
   (a) Favorable geological and hydro-geological formations made of corals, hence rare cases of collapsing and caving in of boreholes and wells.
   (b) Rapid growth of human & livestock population density that have resulted to increase in water demand, hence need of more water points.
   (c) Enlightened population that has formed village water committees through which funding for drilling

boreholes by NGOs and other players is done.

(d) Sufficient political support as many elected representatives appeared to concentrate projects in this sublocation.

(e) Presence of individuals who are somehow well off as they constructed private wells and boreholes which also ended serving the local community.

(f) Existence of good infrastructure ranging from road networks for accessibility and electricity for pumping of water in wells and boreholes as seen in Waa boys and Waa girls secondary schools.

(g) Favorable proximity of the sub location as it boarders the Indian Ocean, Tourist hotels and above all along the Likoni–Ukunda–Lunga Lunga highway. This factor gives it an advantage to be noticed for investment as compared to the other sub locations.

(h) Lack of surface water e.g. streams, rivers, swamps, constructed water pans, subsurface dams among others.

2) MATUGA sub location being the largest of the three entities (almost half) constituting Waa location has got the lowest number of boreholes and dug wells **(**11.27%). Key reasons for the low number of water points in this expansive sub location are;-

(a) Unfavourable geological & hydro-geological formations characterized by loose soils found in the region as very few wells dug and constructed can be fully functional unless reinforced by blocks from inside. Many wells have collapsed and caved in even before completion.

(b) Availability of extensive network of piped water operated by few wealthy and influential persons in the community who collect some money from locals in exchange for water, hence they have made it difficult for the formation of village committees which could have requested for borehole drilling from sponsors.

Political negligence of this sub location as the elected representatives have not shown much commitment to commission water projects in this area.

Biological results for S- samples (sterile)

Table 4: Biological results of the 14 water samples analysed

S. No.	Source of sample	Date sampled	Total coliforms	Feacal coliforms	Residual chlorine	Remarks	Action to be taken
			MPN/100 ml	MPN/100/ml	ppm		
1	K1	6/9/2015	0	0	NIL	Safe	Monitoring
2	K2	6/9/2015	15	4	NIL	contaminated	To be treated
3	K3	6/9/2015	23	4	NIL	Contaminated	To be treated
4	K4	6/9/2015	0	0	NIL	Safe	Monitoring
5	K5	6/9/2015	210	15	NIL	Contaminated	To be treated
6	K6	6/9/2015	7	0	NIL	Contaminated	To be treated
7	K7	6/9/2015	460	20	NIL	Contaminated	To be treated
8	K8	6/9/2015	150	11	NIL	Contaminated	To be treated
9	K9	6/9/2015	15	4	NIL	Contaminated	To be treated
10	M1	6/9/2015	11	0	NIL	Contaminated	To be treated

11	M2	6/9/2015	0	0	NIL	Safe	Monitoring
12	M3	6/9/2015	0	0	NIL	Safe	Monitoring
13	K01	6/9/2015	0	0	NIL	safe	Monitoring
14	K02	6/9/2015	21	4	NIL	contaminated	To be treated

(Source: KIMAWASCO Laboratory)

Physicochemical results for N - samples (Normal)

Physicochemical results of 5 boreholes and 9 hand dug wells (14 in total) collected from Waa location in September 2015 are as shown in the Table 5 below.

Table 5: Physicochemical results of 14 water samples

Sample source	pH units	Color	E.C	TDS	Chloride	Salinity	T. Alkalinity	T. Hardness	Ca^{2+}	Mg^{2+}	Turbidity
	6.5-8.5	**15**	**1500**	**500**	**250**	**250**	**500**	**500**	**65**	**50**	**0-5**
	6.5	**6**	**1500**	**500**	**200**	**250**	**500**	**500**	**75**	**50**	**6**
K1	7.33	2.5	1239	621	170	280.5	346	110	18.63	15.616	0.52
K2	7.27	2.5	1023	508	208	343.2	536	228	64.8	16.592	0.63
K3	7.67	2.5	1505	751	350	577.5	448	268	55.08	32.208	0.87
K4	7.28	2.5	1127	563	220	363	364	192	63.18	8.784	0.82
K5	7.52	2.5	1813	907	380	627	630	348	121.5	11.712	1.06
K6	7.32	2.3	3999	691	1635	2697.8	384	292	85.86	19.52	1.2
K7	7.9	2.5	610	400	30	49.5	296	240	61.56	21.472	3.0
K8	7.67	2.5	498	248	100	165	308	344	100.44	23.424	4.2
K9	7.84	2.5	736	368	70	115.5	274	332	53.46	48.8	0.9
M1	7.36	2.5	278	139	154	254.1	220	84	32.4	0.976	2.0
M2	7.61	2.5	598	297	80	132	440	184	59.94	8.784	1.0
M3	6.98	2.5	180	90	56	92.2	80	0	0	0	0.7
K01	7.35	2.5	1382	691	294	485.1	560	560	162.81	38.552	0.6
K02	7.42	2.5	598	298	200	330	256	248	74.52	15.616	0.7

Summary of Findings

Table 6: Summary table showing comparison of water sample results obtained with W.H.O guidelines and EPA standards

Sample Source	**Compliance status to WHO & EPA standards**	
	Biological parameters	**Physicochemical parameters**
K1	√ (YES)	X (NO)
K2	X (NO)	X (NO)
K3	X (NO)	X (NO)
K4	√ (YES)	X (NO)
K5	X (NO)	√ (YES)
K6	X (NO)	√ (YES)
K7	X (NO)	√ (YES)
K8	X (NO)	√ (YES)
K9	X (NO)	√ (YES)
M1	X (NO)	√ (YES)
M2	√ (YES)	√ (YES)
M3	√ (YES)	√ (YES)

K01		√ (YES)	X (NO)	
K02	X (NO)			√ (YES)

Key

√ (YES) - represents water sample compliance to WHO and EPA guidelines/standards

X (NO) - represents non-compliance to WHO and EPA guidelines/standards.

Conclusion and Recommendations

Conclusion

Performance assessment of the functionality of boreholes and dug wells within Waa location Waa revealed that about 32.39 % of these water points have failed to discharge quality water for drinking due to Negligence from the relevant authorities and agencies in terms of water quality monitoring and low level of community involvement in the development of these water projects.

About 50% of borehole and well water samples did not comply with either of the following investigated parameters of total dissolved solids, total hardness, Ca^{2+}, chloride, electrical conductivity and salinity. Salinity and alkalinity was extremely high in the water samples due to sea water intrusion and dissolved carbonate minerals respectively.

About 64.29% of the analysed samples recorded poor water quality based on WHO (2004) and EPA (2000) guidelines on bacteriological assessment [10].

Recommendations and Suggestion for Future Research

The intervention to achieve water quality in the county will include locating of water sources away from waste disposal sites, proper waste drainage system, establishment of a water resource users association (WRUA), covering of wells to avoid open contamination and construction of communal toilets and pit latrines in Waa location and its environs.

Further research to be carried out in other locations in the county for drinking water analyses is required as levels of contaminants may vary due to different soil types, water chemistry and different human activities.

Potential Conflicts of Interest

The authors declare no conflict of interest.

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Appendices

Appendix (i).WRMA Physicochemical Lab result analysis -March, 2012 (Sample Date: 10/3/12)

Sample source	**Parameter**	**pH units**	**Col or**	**Field E.C**	**Lab E.C**	**TDS**	**Chloride**	**Salinity**	**Turbidity**	**T. alkalinity**	**T. hardness**	**Ca^{2+}**
	WHO guidelines	**6.5-9**	**15**	**2000**	**2000**	**1000**	**600**	**250**	**25**	**500**	**500**	**250**
1.BH-ukundayouth poly	Lab Reg No. 110	7.2	2.5	N/A	733	366.5	40	66	1.62	368	264	67.23
2.BH - Swahili beach hotel. Direct	111	7.6	2.5	2410	2400	1200	596	783.4	0.25	220	368	38.07
3.BH G-Tiwi	112	7.0	2.5	585	547	273.5	76	1254	0.44	194	202	486
4.BH 1-Tiwi	113	6.8	2.5	590	544	272	82	135.33	0.5	194	192	46.17
5.BH-Swahili beach hotel.Tap	114	7.4	2.5	N/A	2220	1110	601	991.65	0.42	324	290	53.46
6.BH- MMarkaz mosq.Diani	115	7.4	2.3	1326	1197	598.5	174	287.1	0.25	436	268	80.19
7.BH-Ngombeni sec. sch	116	7.4	2.5	1293	1268	634	204	336.6	0.46	356	242	9.72
8.BH-Waa Boys sec.Tap	117	7.4	2.5	811	742	371	84	1386	0.24	342	210	2268
9.BH-Hekima high sch	118	7.6	2.5	522	502	251	27	44.55	5.21	274	92	17.01
10.BH-Waa girls sec	119	7.4	2.5	1212	1210	605	202	333.3	0.31	368	198	23.49
11.BH-Kona musa	120	7.4	2.5	789	735	367.5	39	64.35	0.36	376	168	36.45
12.BH-Waa Boys sec	121	7.4	2.5	818	802	401	84	138.6	0.71	330	166	21.06
13.BH-Tahweed mosq. Denyen ye	122	7.2	2.5	818	896	448	99	163.35	0.34	314	150	42.12
14.BH-Bixa Kenyaltd offices	123	7.6	2.5	1660	1663	831.5	101	166.65	0.57	504	122	30.78
15.BH-Kitaru likoni	124	7.4	2.5	1831	1834	917	320	528	0.23	348	490	142.5
16.BH.Tahwe ed islamic. center	125	7.2	2.5	885	884	432	69	113.85	0.63	340	308	116.6

Appendix ii. Unregulated well in Mwachileta andMkokoni (Kitivo sub-location)

Appendix (iii). Nonfunctional BHs: Gulanze, Kitsanze (Kombani sec) and Vibambani (mkokonipri)