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An Assessment of Groundwater Pollution from On-Site Sanitation in Malkerns, Swaziland

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Abstract

Informal settlements are characterized by wide use of septic tanks and pit latrines as a form of sanitation. The high density of such is influenced by rapid population growth resulting in groundwater pollution. An experiment was designed to assess groundwater pollution from on-site sanitation in Malkerns, Swaziland. Six groundwater samples were taken from Malkerns informal settlements boreholes. This was achieved using grab sampling with three replications. The samples were tested for physical, chemical, and bacteriological groundwater quality. Treated tap water was used as a control. The Swaziland Water Services Cooperation (SWSC) laboratory was used for the groundwater testing and analysis. The results were compared to the SWSC drinking water quality guidelines. Results reflected that groundwater physical quality was acceptable, and the chemical quality (nitrates) was within the SWSC drinking water quality guideline (10 mg/L) having the highest value at 4.47 mg/L. Malkerns groundwater was fairly soft (58.77 mg/L). However, the bacteriological quality was not acceptable; all six boreholes were above the 0 per 100 ml SWSC guidelines. This was the case for both the faecal and total coliforms tested. Five out of six boreholes tested positive for faecal coliforms, the highest value being 1354 per 100 ml. The most contaminated borehole by total coliforms had a value of 13000 per 100 ml. Only the treated tap water (control) fell below the SWSC guidelines as expected.

Keywords

Groundwater, Pollution, Onsite, Sanitation, Malkerns, Swaziland

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1. Introduction

Groundwater is found in aquifers below the land surface in the pore spaces of rocks. It flows naturally at springs and, is tapped artificially by the digging of wells (Anonymous, 2012). Groundwater is usually tapped for irrigation and domestic water use. This is common in areas where there is little or no water services provided. However, the aquifer faces a vulnerability of over extraction and pollution.

Groundwater pollution is a change in the properties of groundwater due to contamination by microbes, chemicals, hazardous substances and other foreign particles (Sandhyarani, 2009). Potential groundwater pollution includes municipal, industrial, individual and agricultural sources (Lennetech, 2013). These sources of pollution compromise the quality of groundwater and by extension the health of the water users.

The quality of water, whether used for drinking, domestic purposes, food production or recreational purposes has an important impact on health (WHO, 2013). Water of poor quality can cause disease outbreaks and it can contribute to background rates of disease manifesting themselves on different time scales. Initiatives to manage the safety of water do not only support public health, but often promote

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socioeconomic development and well-being as well.

Contaminated water serves as a mechanism to transmit communicable diseases such as diarrhoea, cholera, dysentery, typhoid and guinea worm infection. WHO estimated that in 2008 diarrhoeal diseases claimed the lives of 2.5 million people (WHO, 2011). This burden for children under five is greater than the combined burden of HIV/AIDS and malaria (Liu *et al*, 2012).

According to Howard *et. al*, (undated) groundwater contamination from decentralized onsite sanitation systems is common, and may be due to inadequate design and maintenance. When pit latrines and septic tanks are badly sited they can pollute the water with nitrates. It is unfortunate that this occurs in proximity to private wells and may become a hazard to the drinking water supplies. This could be exacerbated by high population densities common in developing economies and in low income communities.

Low income communities are associated with high population growth rates and are characterised by high density living, at a low cost. Onsite sanitation is used as an excreta disposal system appropriate to the standard of living. However, the downfall to this according to WHO (1992), is that high density living promotes the spread of hygiene related diseases such as diarrhoea. Therefore, people living in these settlements are prone to water borne diseases related to the method of sanitation used. Onsite disposal sanitation is a threat to subsurface water in that it contributes to groundwater pollution. Pathogens travel in the water in which they are suspended affecting their removal. The removal and elimination of bacteria and viruses is affected by the effluent residence time between the source of contamination and the point of abstraction (Cave and Kolsky, 1999).

Groundwater is known to be the safest source of portable water; however it is susceptible to microbial contamination from *E. coli* bacteria. In Malawi wells were found to be more contaminated with *E. coli* bacteria than boreholes, the boreholes on the other hand were found to contain less pathogens at source compared to household level (Kanyere *et.al*, 2012). Groundwater could be polluted through waste water and onsite disposal sanitation, which includes septic tanks and pit latrines. In India Shivendra and Ramaraju (2015) concluded that pit latrines and septic tanks are common modes of on-site sanitation that are sources of groundwater pollution. Improper wastewater disposal contaminates groundwater resulting in the spread of water related diseases such as typhoid, cholera, dysentery (Kyakula *et al*, 2015). Work by Sorenson *et al* (2015) indicated that 18% of water supplies contained faecal coliforms, 91% of which were located within 10 m of a toilet and 58% had faecal coliforms above detection limit, and sanitary risk scores were high.

Septic tanks could contribute to groundwater pollution, particularly their density and layout. Yates (1985) concluded that, septic tanks contribute the largest volume of waste water, 800 billion gallons per year to the subsurface, and are most frequently reported cause of groundwater contamination associated with disease outbreaks. In Nigeria Adetunji and Odetown (2011) observed that water samples collected from an area characterized by high density septic tanks, was found to be contaminated with coliforms and other bacteria. Pollution from refuse dumps was minimal as compared to pollution influenced by the layout of houses, distances between wells and septic tanks. Areas without sewage treatment plants such as Malkerns are likely to have high levels of contamination in groundwater compared to areas with treatment plants.

Malkerns is one of the semi urban rural towns located in Manzini, Swaziland with geographical coordinates of 26° 34' 0" South, 31° 11' 0" East. It has a considerable influx of people who come looking for employment opportunities. However, without accommodation, they end up in the informal settlements, which are characterized with informal housing, low income residents and poor sanitation facilities. According to Penrose *et al*, (2010) cholera incidence is most closely associated with informal housing, population density and the income level of informal settlements. In such settlements, the people rely on pit latrines and septic tanks for sanitation. The density and proximity of these sanitary facilities may lead to groundwater pollution dependent on the geology.

Acording to Mr Ngubane from the Department of Water Affairs, Government of Swaziland, the Malkerns geology consists of a granite rock with clay to clay loam soils. The rock is said to have thick over bedding, which enables high water movement and good yielding boreholes of 2-5 L/s. Such boreholes may provide the much needed water for the informal settlements of Malkerns.

Informal settlements form a major part of Malkerns and their expansion is based on employment opportunities created by the plantations and the canning industry found in the area. They include Mangozeni, Swazican and Emaphoyiseni, KaGuy flats, Mafini, Stomo and Tingulubeni (Swaziland Central Statistics, 2007). These informal settlements lack proper sewage disposal systems to accommodate the large number of people. They rely on onsite sanitation methods for waste disposal. Despite this, some residents extract groundwater through the use of boreholes for domestic use.

The objective of the study was to assess groundwater pollution from onsite sanitation disposal methods in Malkerns.

2. Methodology

2.1. Research Design

The research was an experiment. Water samples were collected from boreholes in the informal settlements of Malkerns and tested at the Swaziland Water Services Cooperation (SWSC) laboratory. Treated Tap water from Malkerns was used as a control.

2.2. Sampling Procedure

Water samples were collected from each of the boreholes for the areas; Mangozeni, Emaphoyiseni and KaGuy flats in Malkerns. These informal settlements, which used onsite sanitation and accessing groundwater for domestic use in Malkerns formed the sampling frame. A non probability procedure was chosen based on the fact that the assessment of groundwater would be done for the available boreholes.

The procedure involved grab sampling from each borehole which was replicated three times. Polyethylene bottles (350 ml) that were rinsed with distilled water were used for sampling. Sampling was done in the morning for convenience purposes; the procedure was not affected by peak or non-peak hours. It was done during the wet or rainy season. Although sampling during the dry season could have been effective for comparison, it was not done due to limited resources. Purging was not done prior to sampling because the boreholes were active.

2.3. Data Collection and Analysis

To avoid decomposition, the water samples were transported to the SWSC laboratory in a cooler box with ice cubes. The samples were tested for the physical, chemical, and bacteriological quality. The data were analyzed using Microsoft excel computer software, utilizing standard error bars, which were compared against treated tap water and SWSC drinking water guidelines.

2.3.1. Physical Quality Analysis Methods

The physical quality analysis involved performing tests for; pH, turbidity, and colour as outlined next.

a) PH

The table pH meter was used to measure the pH level of water. The electrode was immersed in the sample. Readings were taken after 20-30 seconds after the water readings have stabilized. After each test, the electrode was rinsed with distilled water and wiped dry.

b) Turbidity

Turbidity was determined using the Absorptometric Method, adopted from FWPCA methods for chemical analysis of water and wastes, 275 (1969). The spectrophotometer wavelength was rotated until the small display showed 450 nm and 25 ml of the sample when placed into the cell holder (Hatch company, 1999).

c) Colour

Colour was analysed using the standard Platinum-Cobalt Standard Method as stated by the Standard Methods for the Examination of Water and Waste water. The wavelength of the spectrophotometer was set at 455 nm and the prepared sample placed into the cell holder.

2.3.2. Chemical Quality Analysis Methods

The chemical quality analysis involved performing two tests; nitrates, and hardness.

a) Nitrates

The standard diazotization method using powder pillows was conducted to analyse the amount of nitrate in the water sample.

b) Hardness

Hardness in water is caused by calcium and magnesium compounds, and occurs naturally. Excessive hard water cause excessive soap consumption, whilst soft water tends to be corrosive. Higher levels may cause incrustation of utensils and pipe works. Concentrations greater than 500 mg/L are considered undesirable for domestic use. The Titriemetric method was used to determine the amount of hardness.

2.3.3. Bacteriological Quality Analysis Methods

a) Total coliform

The coliform group is made up of bacteria with defined biochemical and growth characteristics that are used to identify bacteria that are more or less related to faecal contaminants. The total coliforms represent the whole group, and are bacteria that multiply at 37ºC.

Total coliform was determined using reagents, dionized distilled water with the growth medium of 51 g of M-endo ager LES, 25 ml ethanol Abs. and 100 ml of water. The media was boiled. During boiling the media was stirred to avoid the burning of the undissolved media until it was completely dissolved. The media was then allowed to cool to 45-50ºC and dispensed ± 15 ml into each of the 65 mm plastic disposable petri dish. The media was then given 10 minutes to solidify. The freshly prepared plates were stored in an inverted position at 4ºC in a dark area. Upon testing using the membrane filtration procedure discussed above, where 100 ml of the sample was used, all colonies that had a pink to dark-red colour with a metallic surface were counted and the results expressed as total coliforms per 100 ml.

b) Faecal coliform

The term 'faecal coliforms', although frequently employed, is not correct: the correct terminology for these organisms is 'thermotolerant coliforms'. Thermotolerant coliforms are defined as the group of total coliforms that are able to ferment lactose at 44 - 45°C. They comprise the genus *Escherichia* and, to a lesser extent, species of *Klebsiella, Enterobacter,* and *Citrobacter.* Out of these organisms, only *E. coli* is considered to be specifically of faecal origin, being always present in the faeces of humans, other mammals, and birds in large numbers and rarely, if ever, found in water or soil in temperate climates that has not been subjected to faecal pollution.

The analysis of faecal coliform was performed using deionized distilled water with the growth medium being 50 g m-FC broth and 100 ml water. The broth was boiled. During the boiling of the broth, constant stirring was done to avoid burning of the undissolved media. The broth was poured into a 47 mm filter culture plates. Upon testing using the membrane filtration procedure, all green colonies were counted and the results presented as faecal coliforms per 100 ml.

3. Results and Discussion

3.1. Physical Groundwater Results

The physical water quality results included colour, turbidity, and pH.

a) Colour

The groundwater colour was found to be significantly different from each other for all the boreholes. It ranged from a mean of 1.0 mg/L, in borehole one to 11 mg/L for borehole six, as shown in Figure 1.

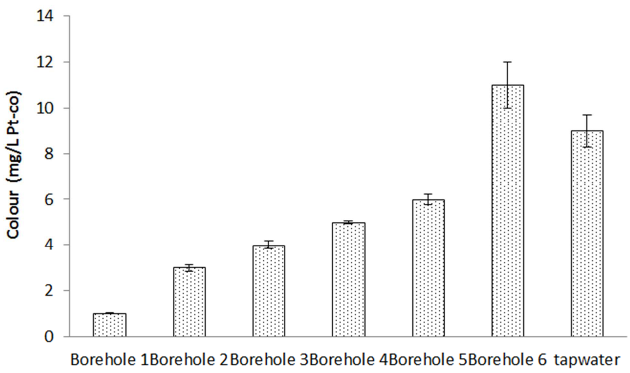

Figure 1. Groundwater colour for the Malkerns boreholes.

The groundwater colour reflected a gradual increase from borehole 1 to borehole six, only to have the treated tap water (control) deviating from the pattern with a mean level of 9 mg/L. According to domestic drinking water guideline levels from SWSC, colour in water should not be greater than 20 mg/L. The results indicated that the groundwater colour for the different boreholes was within acceptable levels. Colour influences the appearance of water and may lack appeal in aesthetics. It is mostly affected by neutral salts and colloidal and non-colloidal acids, and excessive colour in water may result in stains.

b) Turbidity

The groundwater turbidity for borehole 1 (0.35NTU) was not significantly different from that of borehole 2, which had a mean turbidity level of 0.47 NTU (Figure 2). This trend was also evident for boreholes 2 (0.47 NTU) and borehole 4 (0.49NTU) as well as boreholes 5 (0.36 NTU) and borehole 6 (0.43 NTU).

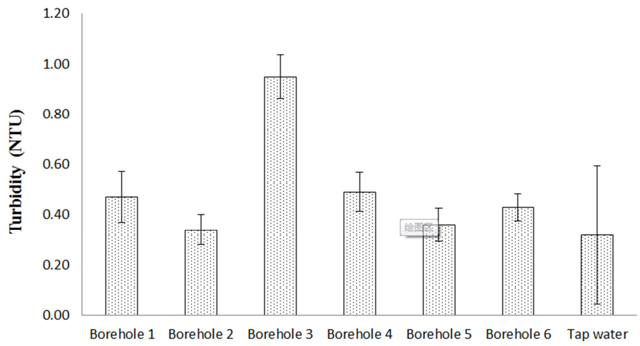

Figure 2. Groundwater turbidity for the Malkerns boreholes.

The groundwater reflected acceptable turbidity levels of less than one NTU (< 1 NTU) in accordance with SWSC drinking water guidelines. Borehole 2 had the lowest mean (0.34 NTU) turbid water; boreholes 1, 4, and 6 had almost the same mean turbidity levels of 0.47 NTU, 0.49 NTU, and 0.43 NTU, respectively. Borehole 3 groundwater was closest to the drinking water guideline limit of 0.95 NTU. This could be due to the type of soil in Malkerns, which is clay loam. This is fine particle sand which has the ability to sieve suspended particles in water. As expected, the control (treated tap water) had the lowest turbidity of 0.32 NTU suspended particles compared to the borehole groundwater.

c) pH

The mean groundwater pH for borehole 1 was the highest (7.89) and significantly different from all the groundwater pH levels from all the boreholes in Malkerns (Figure 3). This trend was reflected in all the borehole groundwater studied, which were all significantly different from each other. The pH for all the boreholes studied ranged from mean levels of 7.06, to 7.89 for borehole 4 and 1, respectively.

The mean pH values for all the boreholes' groundwater was seven, meaning that the water was generally dilute. The groundwater from borehole 1 was slightly alkaline with a mean pH of 7.89, while borehole 4 was nearer to neutral (7.06). The groundwater for boreholes 5 and 6 were not significantly different from each other, both with a mean pH of 7.19. Borehole 2 and borehole 3 had mean pH values of 7.32, and 7.18, respectively. The treated tap water (control) had groundwater with a mean pH of 6.8. The groundwater and tap water pH values were within the acceptable SWSC drinking water guidelines of 6.5 – 8.5. Measuring the pH as a water parameter was important for determining the corrosive level of water. Water with a low pH has a high level of corrosion (WHO, 2010a).

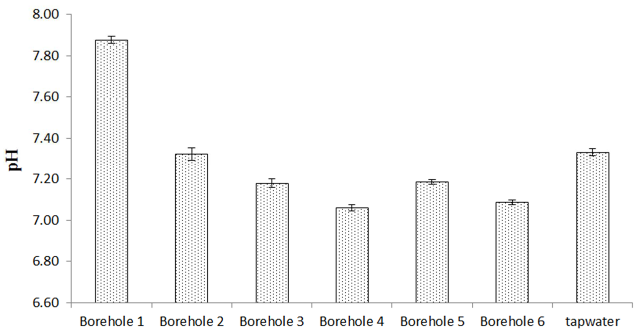

Figure 3. Groundwater turbidity for the Malkerns boreholes.

3.2. Chemical Groundwater Results

Nitrates and hardness were tested for the chemical water quality in the Malkerns boreholes.

a) Hardness

Hardness is the amount of calcium carbonate equivalent per liter (WHO, 2010b). It measures the capacity at which water will react with soap. Hard water will require more soap to reduce lather. Moreover, water containing calcium carbonate at concentration of < 60 mg/L is soft. The results reflected that the groundwater in Malkerns was soft as it ranged from a mean of 48.66 mg/L for borehole 4 to 58.77 mg/L for borehole 1 (Figure 4).

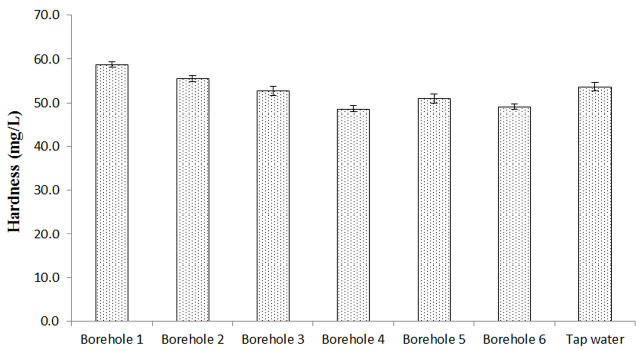

Figure 4. Groundwater Hardness for the Malkerns boreholes.

The groundwater hardness for borehole 4 with a mean of 48.66 mg/L was not significantly different from that of borehole 6, which had a mean of 49.20 mg/L. Both were less than that for the treated tap water or control, which had a mean of 53.67 mg/L. The results met the SWSC drinking water quality guidelines, which indicated that the hardness should be less than five hundred milligrams per liter (< 500 mg/L).

b) Nitrates

The groundwater in the Malkerns boreholes was found to have mean nitrate levels of 1.55 mg/L for borehole 4, which was the lowest, and borehole 3, which had the highest mean nitrate level of 4.2 mg/L (Figure 5).

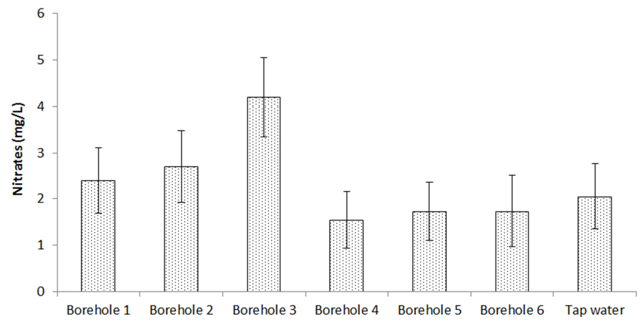

Figure 5. Groundwater Nitrate level for the Malkerns boreholes.

Boreholes 4, 5, and 6 had groundwater levels of nitrate that were not significantly different from each other with mean levels of 1.55 mg/L, 1.9 mg/L, and 1.7 mg/L, respectively. This trend was also observed in the groundwater mean nitrate levels of boreholes 1, 2, and treated tap water, which had nitrate values of 2.4 mg/L, 2.7 mg/L, and 2.05 mg/L, respectively. Borehole 3 had approximately half (4.2 mg/L) the required drinking water guideline levels (10 mg/L) of SWSC. This nitrate level of borehole 3 indicated its close proximity to a pollution source (pit latrine) compared to the other boreholes. Furthermore, the area in borehole 3 might have a steeper slope than the other areas. High nitrate levels in drinking water could result in baby blue syndrome for children less than six months (U.S. EPA, 2006), whereas, incidence of cancer of the brain and central nervous system was found to be higher in areas with higher nitrate levels (Barrett *et al*, 1998).

3.3. Bacteriological Groundwater Results

The bacteriological water quality for Malkerns involved testing for Faecal coliforms and Total coliforms.

a) Total coliforms

As expected, the results reflected that the groundwater Total coliforms ranged from 0 per 100 ml in the treated tap water, which served as a contol, to 13000 per 100 ml for borehole 6 (Figure 6). The groundwater Total coliforms for borehole 1 with a mean of 3654 per 100 ml was not significantly different from that for borehole 2 (2420 per 100 ml). On the other hand the groundwater Total coliforms for the other boreholes were significantly diferent from each other.

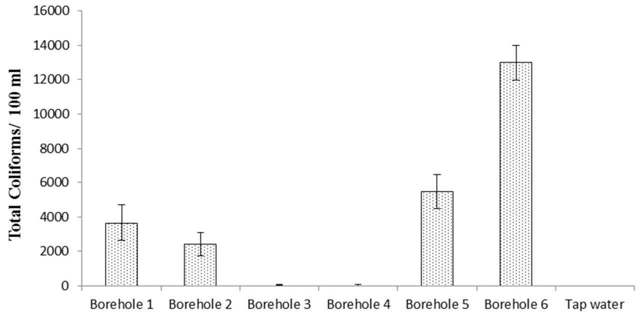

Figure 6. Groundwater Total coliforms for the Malkerns boreholes.

The groundwater was heavily contaminated by coliforms, given the fact that the SWSC guidelines stated that it should be 0 per 100 ml. This condition was as expected, met by the treated tap water, whereas the mean level of contamination in decreasing order was borehole 6 (13000 per 100 ml), borehole 5 (5475 per 100 ml), borehole 1 (3654 per 100 ml), borehole 2 (2420 per 100 ml), borehole 3 (60 per 100 ml), and borehole 4 (41 per 100 ml). This may be attributed to the density of pollution sources in the circumference of each borehole.

Total coliforms are an indicator of water vulnerability to contamination by more harmful microorganisms and are not likely to cause illness. In this situation the results indicated that the groundwater had high susceptibility to contamination by other microorganisms.

b) Faecal Coliforms

Figure 7 reflected that the Faecal Coliforms ranged from 0 per 100 ml for both borehole 3 and treated tap water to 1354 per 100 ml for borehole 5. It is worth noting that the mean variation between the boreholes was low as a result the standard error bars were not visible, thus the graph reflecting the mean Faecal coliform values (Figure 7).

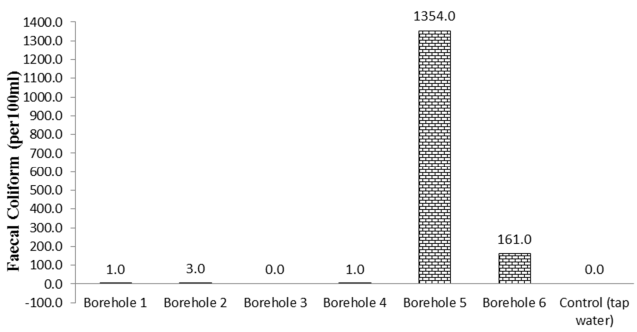

Figure 7. Groundwater faecal coliforms for the Malkerns boreholes

The SWSC drinking water guidelines for feacal coliforms are 0 per 100 ml; the treated tap water and groundwater from borehole 3 met the guidelines. The other borehole sample points do not. Borehole 5 for instance had the most (1354.0 per 100 ml) mean levels of faecal coliform followed by groundwater from boreholes 6 and 2, with mean levels of 161 per 100 ml/L and 3.0 per 100 ml, respectively. Groundwater from boreholes 1 and 4, on the other hand reflected the same value of 1.0 ml per 100 ml faecal coliforms.

The results indicated that groundwater from boreholes 1, 2, 4, 5, and 6 contained pathogenic microorganisms. These are in the form of bacteria, viruses, and protozoa. Malkerns people abstracting groundwater for domestic use from the boreholes could suffer or are suffering from infectious diseases such as gastroenteritis, diarrhea, dysentery and hepatitis.

4. Conclusions

The groundwater from boreholes in Malkerns was tested for physical quality by measuring the parameters pH, turbidity, and colour. The pH levels for the different boreholes were found to fall within the drinking water quality guidelines limit of 6.5-8.5, the least being a mean of 7.06 and the highest 7.89. The turbidity for the groundwater fell below the turbidity limit of 1 NTU as per the SWSC drinking water guideline values. However, the treated tap water (control), as expected had the lowest mean turbidity value of 0.32 NTU. The colour for the boreholes and tap water on the other hand was also within acceptable limits (not greater than 20 mg/L) as per SWSC drinking water guideline values. It could be concluded therefore that, the physical quality for water in Malkerns was satisfactory.

The bacteriological quality of groundwater manifested by Total and faecal coliforms for the boreholes studied in Malkerns was poor and thus not acceptable. Total coliforms for the groundwater in Malkerns were high above acceptable drinking water guidelines, the highest having a mean total of 13000 per 100 ml, whereas the guidelines stated that the total coliforms should be at 0 per 100 ml. This means that the groundwater was highly susceptible to contamination. This is evident in the mean concentration (1354 per 100 ml) of faecal coliforms in the borehole groundwater, which was beyond the SWSC drinking water quality guidelines value of 0 per 100 ml.

The chemical groundwater quality (i.e. nitrates and hardness) for the boreholes in Malkerns was found to be below acceptable drinking water guideline values and therefore acceptable. The mean nitrates were found to be 1.55 mg/L for the lowest borehole groundwater and the highest was 4.2 mg/L. They were however still below the allowable limit (10 mg/L) of nitrates in portable water. Hardness was also below the 500 mg/L mark with borehole one having the highest mean value of 58 mg/L. Based on the results for hardness, it could be concluded that the borehole groundwater in Malkerns was fairly soft (58.77 mg/L).

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