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An assessment of the quality of rooftop rainwater harvested at Nhlambeni, Swaziland

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Research Paper

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ABSTRACT

Rooftop rainwater could be safe provided safety precautions are taken during the capture, storage and distribution. Despite the precautions taken, rooftop rainwater can be polluted, hence this study. An experiment was conducted to purposively target the quality of rooftop rainwater harvested by 81 households in Nhlambeni. It was designed to determine the storage facilities and catchment materials used for rooftop rainwater harvesting, and to determine the physical and biological quality of the rooftop rainwater harvested.It had four treatments; corrugated iron, corrugated iron with concrete blocks, painted corrugated iron and tiles with two replications. The Swaziland Water Services Cooperation (SWSC) treated tapwater was used as a control. The parameters investigated were Biological and physical. Rainwater samples were collected at the top and bottom of the storage tanks using two sterilised glass bottles. Rainwater analysis results were compared to the SWSC drinking water guidelines. Data were analyzed using Microsoft Excel computer software, utilizing standard error bars. The results indicated that the rooftop rainwater storage facilities used by the 81 households were mostly (98.8%) PVC tanks and one (1.2%) metal storage tank. The catchment materials were corrugated iron sheets (95.1%) and Tiles (4.9%). The biological quality of the harvested rainwater was within the acceptable level (> 100 counts per 100 ml).Total and faecal coliforms had total mean levels of 15.46/100 ml and 11.63/100 ml, respectively. It was concluded that the Physical rainwater quality reflected that the rainwater was within acceptable quality ranges (>25NTU for turbidity and between 6.5 and 8.5 for pH). Turbidity, pH and temperature had total averages of 12.23 NTU, 6.54 and 12.3^{0}C, respectively. It was recommended that the rooftop rainwater storage tanks should be flushed during the dry season when they are empty to minimize contamination during the subsequent rainwater harvesting season.

Key words: Rainwater harvesting, Rooftop catchments, Water quality.

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INTRODUCTION

Nhlambeni is located at 26.350981 S and 31.231077 E with an average altitude of 430 m above sea level. It has a population of about 12,466 people, and 1,919 homesteads. The area receives an average annual rainfall of 619.3 mm and most of it is received from October to March (Government of Swaziland, 2011). Some of the rainfall received at Nhlambeni is harnessed at household level for domestic use through rooftop rainwater harvesting.

There are many processes by which the earth loses water in the water cycle and it is through snowing and rainfall that brings the water back to the earth. At this point precipitation water is relatively clean and could be collected for use with minimal capital investment, which can be afforded by people even in rural areas. Rainwater harvesting can be described as the small-scale concentration, collection, storage, and use of rainwater runoff for productive purposes. Rivers represents a small portion of annual precipitation; hence one method of obtaining water outside the river systems is to harness rainwater before it is exposed to evaporation (Pacey and Cullis, 1986).

Rainwater can be stored in some natural or artificial container either for immediate use or use before the onset of the next season (Singwane and Kunene, 2010). Rainwater is relatively cheap, as it requires minimum treatment and needs little reticulation systems (Minister for Water Resources Management and Development Kenya, Undated). It does not make sense to allow water to flow freely on the earth surface to cause environmental disasters such as flooding, landslides and soil erosion when it could be harvested and used productively. Rainwater could be harvested for industrial purposes, agricultural production, groundwater recharge and domestic applications and most recently to cope with the devastating effects of climate variability and climate change. The quality of the harvested water will thus drive the application or use. Water quality is an important aspect of human health, (in urban or in rural areas) and it improves the level of sanitation. Safe drinking water is good for health and unsafe drinking water could cause diseases like trachoma, cholera, typhoid and schistosomiasis (Mwendera, 1999).

Gas emissions in the atmosphere often pollute rainwater. Rainwater in the atmosphere reacts with gaseous pollutants such as carbon dioxide to form carbonic acid. It also reacts with sulfur dioxide from industries and volcanic reaction which makes the rainwater to become acidic and this cause corrosion, bitterness and acid rains (Gerish, undated). These pollutants alter the quality of the water which might put the life of the users at stake if they are in access. It is worth noting that pollutants could occur throughout the rainwater harvesting system i.e. at interception in the catchment, conveyance and storage. Methods of water interception, in general use include corrugated galvanized iron roofs, courtyards, ground (surface) catchments and tiles which have the advantage of being durable and require minimal maintenance (United Nations Environmental Programme, 1983). Thatch has been found to be a health hazard to human since it changes the colour of the water, making it prone to contamination(Worm and Hattum, 2006; Efe, 2006).

According to WHO (Undated) safe drinking water should be free from pathogenic organisms, and compounds that have adverse effect on human health. It should be clear or colourless and not saline. There should be no compounds which will give a bad taste, or smell or cause corrosion to the water supply system. The water should not stain clothes when used for washing or laundry purposes. During winter when there are no rains, dust settles on rooftops; leaves and bird dropping usually accumulates. When the summer rains begin, the dirt is washed into the storage and later settles to the bottom of these materials causing the growth of bacteria and other microorganisms (Hofkes, 1981). In rural areas the rooftops are not properly designed as a result concrete blocks, iron bars, and tyres are used to stabilize the rooftop, thus preventing it from being blown off by wind. Small elements of these materials contribute to the contamination of the rainwater. Helmreich and Horn (2008) stated that the catchment itself might be a source of heavy metal and organic substances that pollutes the rooftop rainwater harvested.

Rainwater harvesting began in Europe where earth and masonry dams were constructed, not only to store runoff but also to raise the general water level. Rooftop rainwater harvesting is one main form of water collection that relatively obtains clean safe drinking water (Vilane et al., 2010). In this regard, Doyle (2006) also stated that most rainwater collected on roof yard systems generally matches the WHO standards for drinking water, but only if the first flush water is removed before entering the storage. Despite the safe quality of rooftop harvested rainwater, compared to surface water sources like rivers, Swaziland still lacks the infrastructure to provide safe drinking water for domestic use in rural areas (Vilane and Mwendera, 2011), hence this study.

The objectives of the study were to determine the storage facilities and catchment materials used for harvesting rooftop rainwater in Nhlambeni, and to determine the physical and biological quality of the rooftop rainwater harvested in Nhlambeni.

METHODOLOGY

Research design

The research was an experiment designed to purposively target 81 households that practised rooftop rainwater harvesting in Nhlambeni. It had four rooftop catchment treatments which were corrugated iron sheets (CI), corrugated iron sheets with concrete blocks (CIB), corrugated iron sheets painted (CIP) and tiles (T). The SWSC treated tap water was used as a control. In all the treatments water samples were taken from PVC tanks with two replications.

Sampling procedure

Sampling from water storage tanks should be conducted using a tank sampler to facilitate sampling at various depths (Cole-palmer, undated). However, it was not utilized during the study due to resources limitations. Rooftop harvested rainwater samples were collected from the PVC storage tanks that were used. The water samples were collected from each treatment; CI, CIB, CIP and T and replicated two times. It was conducted at the top of the roof top water harvested PVC storage tanks and at the bottom through the water tank tap. Two sterilised glass bottles (250 ml and 500 ml) were used for sampling. The 250 ml bottles were used to sample water which was used for bacteriologic analysis, and the 500 ml bottles were used to take samples for the physical analysis. At each sampling site, four bottles (two 250 ml and 500 ml) were used. A set of 250 ml and 500 ml were used to sample at the top of the tank, then another set at the bottom of the tank. This procedure was repeated at each sampling station. Sampling was done in the morning when the water temperature was still low. The sampling was done in October when the summer rains began after the first storm, then in January in the middle of the rainy season and at the end of the rainy season in March.

Storage facilities and roof top catchment materials used for RWH*:* These were done through observations and noted in a field book during sampling.

Data collection and analysis

To avoid decomposition, the samples were transported to the Swaziland Water Services Cooperation Laboratory in a cooler box with ice cubes. The samples were tasted for physical and bacteriological quality. The data was analysed using Microsoft excel computer software 2010. The means were expressed in standard error bar graphs, and compared against SWSC treated tap water and the Swaziland Water Services Cooperation drinking water guidelines.

Physical rainwater quality analysis: The physical quality analysis involved performing tests for; pH, turbidity and temperature.

pH

A pH meter was used on site to determine the water pH. Two electrodes were rinsed with distilled water and inserted in every 500 ml bottle of the samples. Readings were taken after 20-30 seconds after the water readings on the meter have stabilized. The electrodes were rinsed with distilled water, after each reading.

Turbidity

Turbidity was determined by titrating 25 ml of the 500 ml water sample into a test tube. This was done for all the samples on 500 ml bottles. A sample of 25 ml distilled water was first used to calibrate the spectrometer until it showed 450 nm and 0.0 for turbidity readings. Each sample was titrated into the 25 ml measuring cylinder then placed into a cell holder where later readings were displayed on the screen.

Temperature

A clinical thermometer was used to determine the water temperature in all the 500 ml samples on site. This was done through inserting the thermometer in the sample until the readings stabilized before taking a reading.

Bacteriological rainwater quality analysis*:* The bacteriological quality analysis involved performing tests for; total and faecal coliforms.

Total coliforms

The coliform group is made up of bacteria with defined biochemical and growth characteristics that are used to identify bacteria and are more or less related to faecal contaminants. The total coliforms represent the whole group, and it is bacteria that multiply at 37^0C.Total coliforms were determined using reagents, deionized distilled water with a growth medium of 51g of M-endo ager LES, 25 ml ethanol Abs. and 100 ml of tap water. The media was then boiled. During the process of drying, the media was stirred to avoid burning the undisolved media until it was completely dissolved. It was then allowed to cool to a temperature range between 45 - 50^0C and then dispense ±15 ml in each of the 47 mm plastic petri dishes. 100 ml of water from 250 ml samples were filtered through a 47 mm filter membrane. The filter membranes were then placed on the petri dishes with the media, a procedure that was done for all the samples in 250 ml bottles. The petri dishes with the filtrates were placed in an oven placed at constant room temperature for 24 hours. Upon testing using the membrane filtration procedure discussed on the previous page, 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.

Faecal coliforms

Faecal coliforms are the group of total coliforms that are able to ferment lactose at 44 - 45 ^{0}C. They include the genus *Escherichia* and, to a lesser extent, species of *klebsiella*, *Enterobactor,* and *Citrobactor.* Out of these

Table 1. Rooftop rainwater harvesting storage used at Nhlambeni (N = 81).

Storage tank	Total	
	N	%
Metal	1	1.2
PVC	80	98.8
Total	81	100

Table 2. Rooftop catchment material used for rainwater harvesting (N = 81).

Rooftop material	Total	
	N	%
Corrugated iron sheets	60	74.1
Corrugated iron sheets with concrete blocks	10	12.3
Corrugated iron sheets painted	7	8.6
Tiles	4	4.9
Total	81	100

organisms, only *E.coli* is considered to be a faecal origin, being present in human faeces, other mammals, and birds in large numbers and rarely if ever, found in water or soil in temperate climates that have not been subjected to faecal pollution. The analysis of faecal coliforms was done using deionized distilled water with the growth medium being 50 g m-FC broth and 100 ml of water. The broth was boiled.

During the boiling process constant stirring was done to avoid burning of the undisolved media. 100 ml of water from 250 ml samples were filtered through a 47 mm filter membrane. The filter membranes were then placed on 47 mm petri dishes with the media, a procedure that was done for all the samples in all the 250 ml bottles. The petri dishes with the filtrates were placed in an oven at 45^0C for 24 hours. Upon testing using the filter membrane procedure discussed above, where 100 ml of the sample was used, all colonies that had a blue colour were counted and the results expressed as faecal coliforms per 100 ml.

RESULTS AND DISCUSSION

Storage facilities used for RWH

The rooftop rainwater harvesting storage facilities used by the 81 households studied in Nhlambeni were Metal and PVC tanks (Table1). The PVC tanks were the most predominant (98.8%) storage facilities used and the remaining one (1.2%) was a metal storage tank. This could be attributed to the availability of these tanks in the various hardware retail outlets in Manzini city, which is 15 km away from Nhlambeni.

Rooftop catchment material used for RWH

There were two main types of catchment material (Corrugated iron sheets and Tiles) used by the 81 households for rooftop rainwater harvesting at Nhlambeni (Table 2). Corrugated iron sheets were observed to be the most (95.1%) predominant roof catchment material and the remaining four (4.9%) households harvested rainwater from roof catchments with Tiles.

There were three variations of corrugated iron sheets that were identified as corrugated iron sheets, corrugated iron sheets with blocks and corrugated iron sheets that were painted, which were utilized by 74.1%, 12.3% and 8.6% households, respectively. The dominance of corrugated iron sheets could be due to its ease of installation and relatively low cost per unit compared to roof tiles.

Rooftop rainwater bacteriological quality results: The bacteriological quality of the rooftop harvested rainwater results included total coliforms and faecal coliforms a detailed next.

Total coliforms

The total coliform results indicated that at some point during the rainy season there was no significant difference among the five rooftop catchment treatments. Figure 1 reflected that there was no significant difference in the total coliforms of the rooftop harvested rainwater between the treatments it was harvested from.

The rooftop rainwater harvested from CIcatchments contained the highest (37.2 per 100 ml) mean amounts of total coliforms for all the months. The rooftop rainwater harvested from CIP, CIB, T catchments and tap water had means of 16.0, 10.8, 7.0 and 6.3, respectively per 100 ml of water. There was no significant difference between the rooftop rainwater harvested from CI and CIP catchments. Corrugated iron (CI) catchment harvested rooftop rainwater was significantly different from all the treatments. Rooftop rainwater harvested from CIB, CIP, T and treated tap water was not significantly different. The presence of total coliforms in rainwater means there was a high risk of contracting water borne diseases. Total coliforms mostly come from faecal matter and their presence in the samples was an indication of pollution in the rooftop harvested rainwater. It also indicated faecal contamination and poses a potential health hazard to human life (New York State Department of health, undated).

Faecal coliforms

Figure 2 indicated that rooftop rainwater harvested from

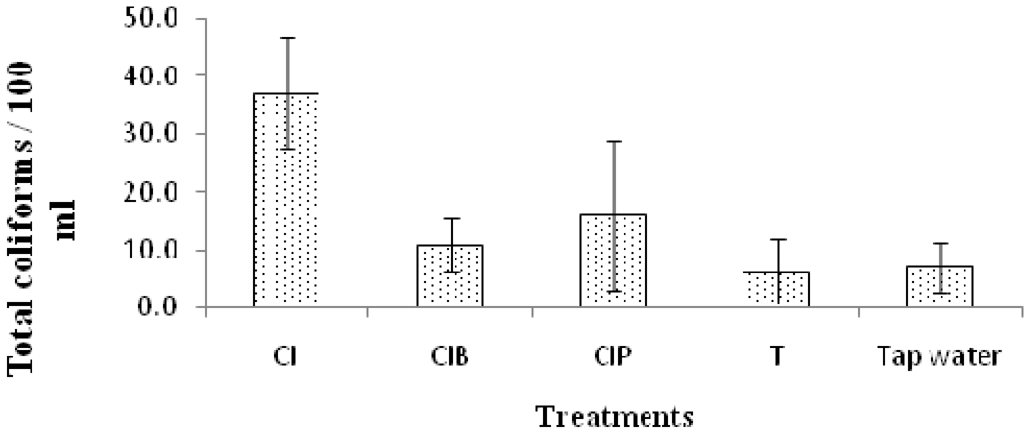

Figure 1. Total coliforms for the rooftop rainwater harvested at Nhlambeni.

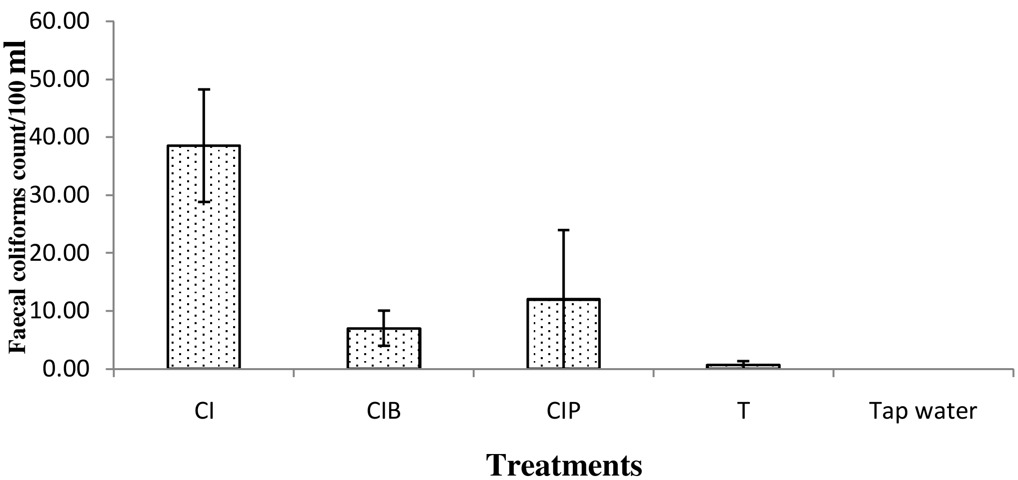

Figure 2. Faecal coliforms for rooftop rainwater harvested at Nhlambeni.

CI catchment was significantly different from all the catchment treatments. Total coliforms in all the treatments were not the same. Corrugated iron catchment harvested rainwater had a mean of 38.5/100 ml, followed by CIP 12.00/100 ml, CIB 7.00/100 ml, T 0.67/100ml. Tap water had 0.00/100 ml. Rooftop rainwater harvested from CIB and CIP catchments were not significantly different in their feacal coliforms. There was also no significant difference between rainwater harvested from CIP catchments and tap water, whilst the control (treated tape water) was significantly different from rooftop rainwater harvested from CIB roof catchments.

The Swaziland Water Services Cooperation drinking water guidelines values of 0/100 ml was only met by the treated tap water. The levels of faecal coliforms were within the allowable SWSC guidelines for drinking water. These low levels of faecal matter may be influenced by human population increase in the area. Bushes were cleared for the construction of houses, which are usually a source of leaves and faecal matter from birds which hibernate there.

Bacteriological water quality variation

i. *Total coliforms*

Figure 3 indicated that there were low (10 counts/ 100 ml) Total coliforms at the beginning of the rains.This could be

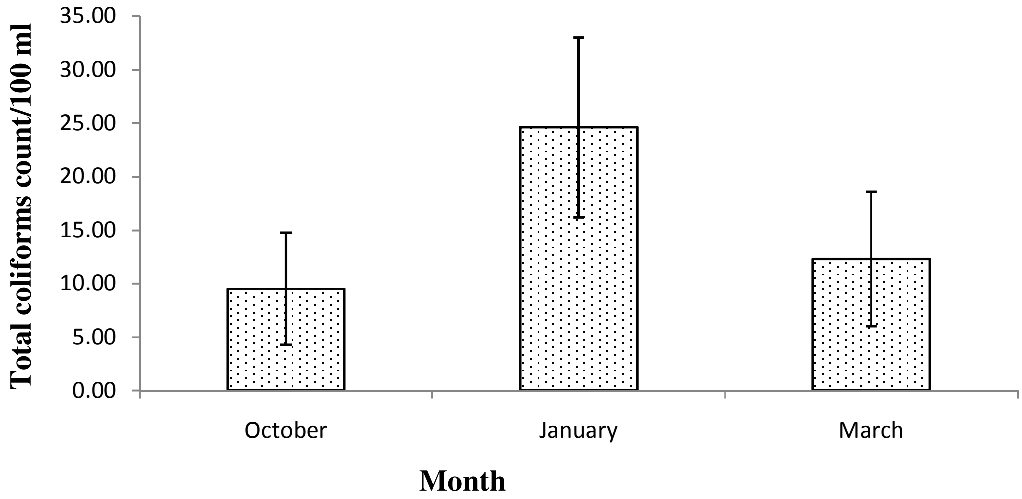

Figure 3. Total coliforms in the rooftop harvested rainwater at Nhlambeni.

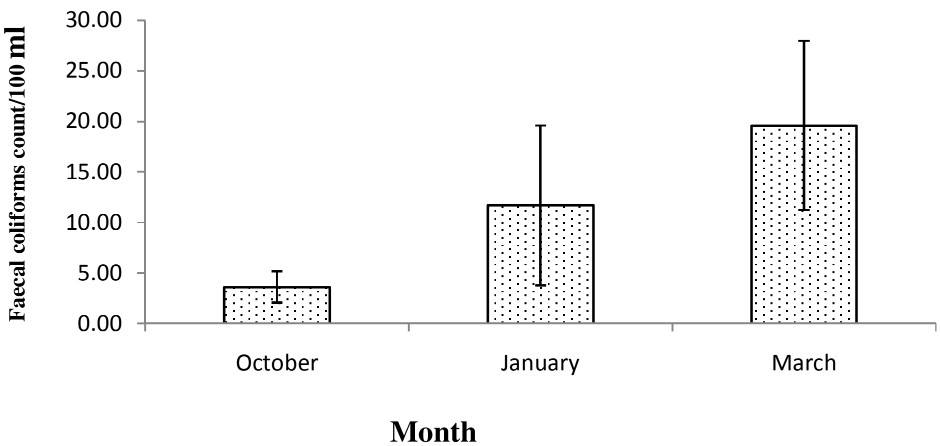

Figure 4.Faecal coliforms in the rooftop rainwater harvested at Nhlambeni.

due to a lot of matter that collected on the catchment area during the dry season, which later became active bacteria as was evident in January. There was a significant difference between the Total coliforms in the rooftop harvested rainwater in October and in the rooftop harvested rainwater in January. However, there was no significant difference in total coliforms between the rooftop harvested rainwater in January and in March.

The mean total coliforms for the months were 24.6/100 ml, 12.3/100 ml and 9.5/100 ml for January, March and October, respectively. It is worth noting that in March the total coliforms for the rooftop harvested rainwater were not significantly different from October and January. The rooftop harvested rainwater in October was significantly different from that harvested in January. In March the rooftop harvested rainwater had Total coliforms that decreased. This could be attributed to the rains which were received during the month, which had an effect on the stored water. As rainwater was added on the already stored water, it diluted the contents in storage, thus decreasing their Total coliform level.

ii. Faecal coliforms

The faecal coliforms were low (3.60 per 100 ml) in the beginning of the rainy season in October but increased as the rainy season continued (Figure 4). The faecal

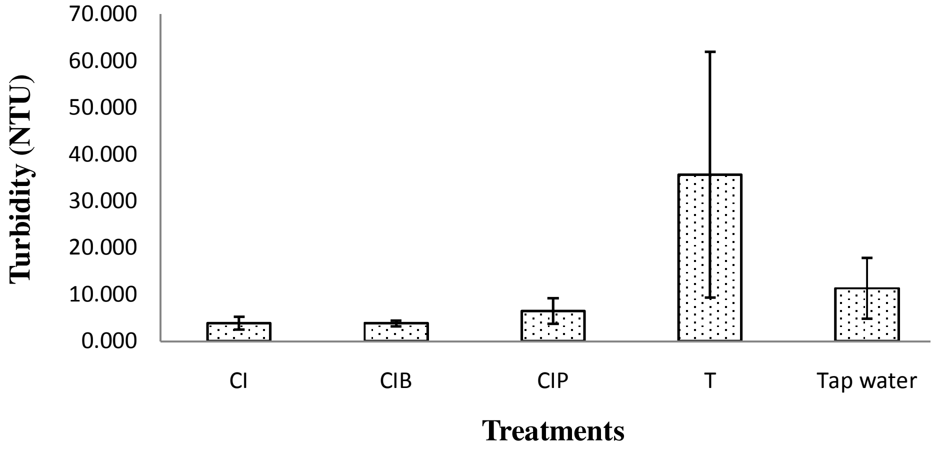

Figure 5. Turbidity for rooftop rainwater harvested at Nhlambeni.

coliform counts for the rooftop harvested rainwater were 3.60, 11.70 and 19.60 per 100 ml in October, January and March, respectively. This could be attributed to bacteria growing in the rainwater storage tanks since most of them were not cleaned or flushed before harvesting water during the new rainy season.

There was no significant difference in faecal coliforms of the rooftop harvested rainwater in October and that harvested in January. This trend was also observed between January and March, but there was a significant difference between the rooftop harvested rainwater in October and that harvested in March. The rooftop rainwater harvested in October had the lowest (3.60/100 ml) level of faecal coliforms. This could be due to the high rainfall received at the beginning of the season. The bacteria in the storage tank had not developed into notable levels. As the rains continued the temperature levels were also high. High temperatures influence the multiplication of bacteria. The presence of faecal coliforms indicated that there were pathogenic microorganisms in the form of bacteria, protozoa and viruses. Using this water for domestic purposes could cause infectious diseases such as gastroenteritis, dysentery and hepatitis to users.

Physical rainwater quality results: The physical water quality results included turbidity, pH and temperature.

Turbidity

Figure 5 indicated variation in turbidity among the rooftop harvested rainwater. There was no significant difference between the rooftop rainwater harvested from CI catchments and that harvested from CIB catchments since they had the same turbidity levels of 3.83 NTU. Rooftop rainwater harvested from roof tile catchments (T) was not significantly different from tap water. The turbidity levels for rooftop harvested rainwater from CIP catchments was 6.50 NTU, T was 35.67 NTU and treated tap water had turbidity levels of 11.33 NTU.

The rooftop harvested rainwater reflected unacceptable levels of turbidity (< 25NTU) in accordance with the Swaziland Water Services Cooperation minimum guidelines. This was due to small particles suspended in the water. In addition, some could have settled at the bottom of the tank, which was washed by rain into the storage tank. These high levels of turbidity may cause gastro-intestinal irritation.

pH

The mean pH of the rooftop rainwater harvested from some of the rooftop catchments was not significantly different from each other (Figure 6). Tap water had the highest (6.78) pH and it was significantly different from all the other rooftop harvested rainwater. There was no significant difference in pH between the rainwater harvested from CI, CIB, CIP and T catchments. The rooftop harvested rainwater reflected acceptable levels of pH, which were within the range of the Swaziland Water Services Cooperation minimum guidelines (SWSC, 2012). Based on the Ph scores of the analyzed samples, all the rainwater harvested from the rooftop catchments was acceptable for human consumption.

Temperature

The results indicated that there was no significant

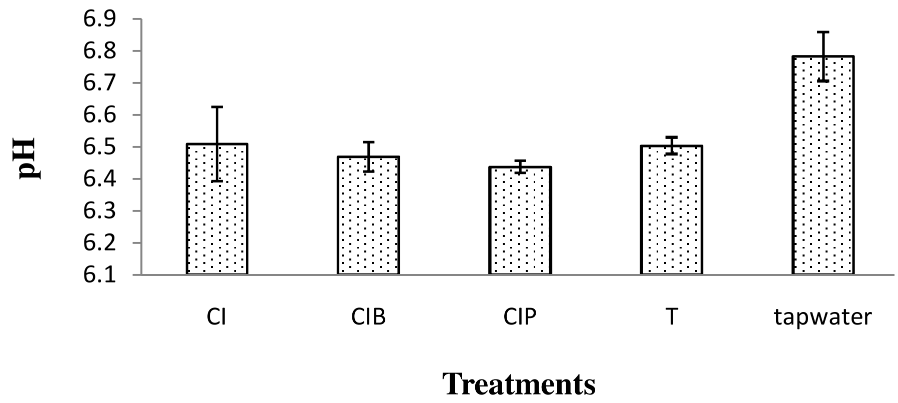

Figure 6. Rooftop rainwater pH for the rainwater harvested at Nhlambeni.

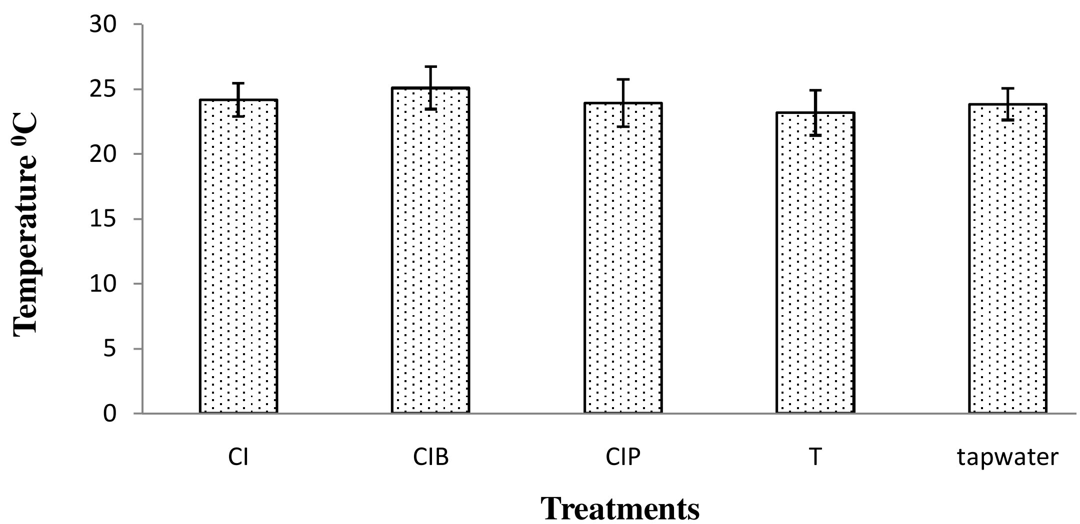

Figure 7. Rainy season rooftop rainwater temperature at Nhlambeni.

difference between the water temperatures for the rooftop harvested rainwater in Nhlambeni (Figure 7). The rooftop rainwater harvested from CIB catchments had the highest temperature of 25.8 ^{0}C. This could be attributed to the concrete blocks that had some soil particles which retained temperature. The storage tank was positioned such that it absorbed most of the sun's radiation. The rooftop rainwater harvested from CIP, T, CI catchments and treated tap water had temperatures of 23.9 ^{0}C, 23.1 ^{0}C, 24.2 ^{0}C and 23.8 ^{0}C, respectively during the rainy season. Temperature promotes the growth bacteria, if the temperature increases, more bacteria will develop, thus the reason for the high total and faecal coliforms in January could be due to the water high mean temperature.

CONCLUSIONS AND RECOMMENDATION

The facilities that were used for the storage of rooftop harvested rainwater by the 81 households studied in Nhlambeni were mostly PVC tanks that were used by 98.8% households and 210 Litre metal drums that were used by one (1.2%) household. The metal drums were essentially by-products of the petroleum industries. The storage tanks were not cleaned as a result fresh water was harvested into dirty storage tanks from the previous rainy season.The catchment materials from which the rooftop rainwater was harvested from included corrugated iron sheets (CI), Corrugated Iron sheets with concrete Blocks (CIB) Corrugated iron sheets painted (CIP), and tiles (T), which were utilized by 74.1%, 12.3%, 8.6% and 4.9% households, respectively. It is worth noting that the concrete blocks were reportedly used to provide weight on the roof to help prevent it from being blown by wind. The physical parameters included turbidity, pH and temperature, which were found to have means of 12.23 NTU, 6.54 and 12.3 ^{0}C, respectively. The bacteriological parameters, identified as total and faecal coliforms were found to have means of 15.46/100 ml and 11.63/100 ml, respectively. There were traces of faecal and total coliforms in the rooftop harvested rainwater which is a health hazard to human health. The mean turbidity was within the acceptable range (< 25 NTU) for human consumption. The mean water pH was within the allowable levels which are pH 6.5 and 8.5. The average temperature was low (12.3 ^{0}C) thus inhibiting bacterial multiplication. Rainwater was acceptable for human consumption since all the tested parameters were within the allowable guideline values.

The rooftop rainwater storage tanks should be flushed during the dry season when they are empty to minimize water contamination during the subsequent rainwater harvesting season.

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